☆ Mrs J H Schaafer.
26 June 98.

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A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN THE ENGINEERING PROFESSIONS AND TRADES OR FOR THOSE WHO DESIRE INFORMATION CONCERNING THEM. FULLY ILLUSTRATED AND CONTAINING NUMEROUS PRACTICAL EXAMPLES AND THEIR SOLUTIONS

PIPES AND FITTINGS
STEAM-FITTING ACCESSORIES
RADIATORS AND COILS
HEATING AND POWER BOILERS
BOILER FITTINGS
PRINCIPLES OF HEATING
PRINCIPLES OF VENTILATION

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PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools, is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one, or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice—together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the

indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one to select the proper formula, method, or process and in teaching him how and when it should be used.

This volume treats on the subjects of pipes and fittings, steam-fitting accessories, radiators and coils, heating and power boilers, boiler fittings, principles of heating, and principles of ventilation. The subject of heating and ventilation, as embraced in the foregoing, was written from the heating engineer's point of view, and the treatment is thoroughly practical. In describing and illustrating the different apparatus, we have endeavored to select such devices as are most suitable to illustrate certain principles of construction. In this way, the principles underlying the construction and operation of the numerous kinds of apparatus used in the heating trade can easily be understood through a knowledge of those described and illustrated in these books. The volume is particularly valuable to architects, architectural draftsmen, building superintendents, heating engineers, and journeymen steam fitters, and helpers.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 16, page 26, will be readily found by looking along the inside edges of the headlines until § 16 is found, and then through § 16 until page 26 is found.

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PIPES AND FITTINGS

PIPES

WROUGHT-IRON PIPE

INTRODUCTION

1. In the erection of steam-heating apparatus, pipes and various fittings having a shape suitable for the requirements are used. The fittings are made of cast iron, brass, malleable iron, and steel castings, tapped or otherwise finished to connect the pipes together. The pipes used in most of the work are of wrought iron or steel.

2. For connecting pipes to the fittings, screw threads are generally used. These threads have a standard number of threads to the inch for different sizes of wrought-iron and steel pipe, and the fittings are tapped with threads to suit the thread of the pipe. The threads are made with a slight taper, the thread in cutting starting with a small groove, increasing in depth until a full thread is cut. They are usually made right hand; that is, the pipe in screwing into the fitting is turned to the right. Left-hand threads are also used on pipe and in fittings; in buying pipe, the left-hand thread must be specially ordered, as the regular pipe on the market is threaded only right hand.

TABLE I

DIMENSIONS OF STANDARD WROUGHT-IRON PIPE

Diameter			Thickness.	Circumference		Transverse Areas			Length of Pipe Per Square Foot of		Length of Pipe Containing Cubic Foot.	Nominal Weight Per Foot.	Number of Threads Per Inch of Screw.
Nominal Internal.	Actual External.	Approximate Internal Diameter.		External.	Internal.	External.	Internal.	Metal.	External Surface.	Internal Surface.			
Inches	Inches	Inches	Inches	Inches	Inches	Square Inches	Square Inches	Square Inches	Feet	Feet	Feet	Pounds	
1/8	.405	.270	.068	1.272	.848	.129	.0573	.0717	9.440	14.150	2513.000	.241	27
1/4	.540	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.490	1383.300	.420	18
3/8	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.730	751.200	.559	18
1/2	.840	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.130	472.400	.837	14
3/4	1.050	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.000	1.115	14
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.900	1.668	11½
1¼	1.660	1.380	.140	5.215	4.335	2.164	1.4960	.6680	2.301	2.768	96.250	2.244	11½
1½	1.900	1.611	.145	5.969	5.061	2.835	2.0380	.7970	2.010	2.371	70.660	2.678	11½
2	2.375	2.067	.154	7.461	6.494	4.430	3.3560	1.0740	1.608	1.848	42.910	3.609	11½
2½	2.875	2.468	.204	9.032	7.753	6.492	4.7840	1.7080	1.328	1.547	30.100	5.739	8
3	3.500	3.067	.217	10.996	9.636	9.621	7.3880	2.2430	1.091	1.245	19.500	7.536	8
3½	4.000	3.548	.226	12.566	11.146	12.566	9.8870	2.6790	.955	1.077	14.570	9.001	8
4	4.500	4.026	.237	14.137	12.648	15.904	12.7300	3.1740	.849	.949	11.310	10.665	8
4½	5.000	4.508	.246	15.708	14.162	19.635	15.9610	3.6740	.764	.848	9.020	12.490	8
5	5.563	5.045	.259	17.477	15.849	24.306	19.9900	4.3160	.687	.757	7.200	14.502	8
6	6.625	6.065	.280	20.813	19.054	34.472	28.8880	5.5840	.577	.630	4.980	18.762	8
7	7.625	7.023	.301	23.955	22.063	45.664	38.7380	6.9260	.501	.544	3.720	23.271	8
8	8.625	7.982	.322	27.096	25.076	58.426	50.0400	8.3860	.443	.478	2.880	28.177	8
9	9.625	8.937	.344	30.238	28.076	72.760	62.7300	10.0300	.397	.427	2.290	33.701	8
10	10.750	10.019	.366	33.772	31.477	90.763	78.8390	11.9240	.355	.382	1.820	40.065	8
11	11.750	11.000	.375	36.914	34.558	108.434	95.0330	13.4010	.325	.347	1.510	45.028	8
12	12.750	12.000	.375	40.055	37.700	127.677	113.0980	14.5790	.299	.319	1.270	48.985	8
13	14.000	13.250	.375	43.982	41.626	153.938	137.8870	16.0510	.273	.288	1.040	53.921	8
14	15.000	14.250	.375	47.124	44.768	176.715	159.4850	17.2300	.255	.268	.903	57.893	8
15	16.000	15.430	.285	50.260	48.480	201.060	187.0400	14.0200	.239	.248	.770	62.000	8

STANDARD WROUGHT-IRON PIPE

3. Standard wrought-iron pipe is made in the sizes and weights shown in Table I. A large amount of steel pipe is made, and sometimes sold as wrought-iron pipe. Its general appearance is the same as that of wrought-iron pipe, but on close examination the grain of the metal will show a finer fiber than wrought iron. Steel pipe can also be distinguished by threading it with the dies, as the closer grain and tendency to unevenness in its composition cause the threads to chip and break, while the wrought-iron pipe has a malleability that allows perfect threading. The pipe is sold in lengths averaging about 18 to 20 feet. The small sizes are shipped in bundles convenient for handling. All pipe from $\frac{1}{8}$ inch to $1\frac{1}{4}$ inches nominal diameter is butt-welded, and all pipes $1\frac{1}{2}$ inches in diameter and larger are lap-welded. The standard weight pipe is tested by hydraulic pressure to 300 pounds per square inch for the butt-welded sizes, and to 500 pounds pressure for the lap-welded sizes. The safe-working pressure for standard pipe is about 100 pounds per square inch; this allows a fair margin of safety to provide for deterioration of the structure of the metal, by expansion and contraction, and for corrosion.

EXTRA-STRONG WROUGHT-IRON PIPE

4. Extra-strong wrought-iron pipe has the same external dimensions as the standard pipe; the wall of the pipe is made heavier, which reduces the size of the bore. This should be taken into account where pipe of a stated size is required. Extra-strong pipe is always shipped without threads or couplings, unless otherwise ordered. This pipe is used for high steam pressures and for heavy pressures in hydraulic work. Its sizes and weights are given in Table II.

DOUBLE EXTRA-STRONG WROUGHT-IRON PIPE

5. Double extra-strong wrought-iron pipe has a thicker wall than extra-heavy tubing. Its external diameter, however, is the same as that of standard wrought-iron

TABLE II

STANDARD DIMENSIONS OF EXTRA-STRONG WROUGHT-IRON PIPE

Diameter			Thickness.	Circumference		Transverse Areas			Length of Pipe Per Square Foot of		Nominal Weight Per Foot.
Nominal Internal. Inches	Actual External Inches	Approximate Internal Inches	Inches	External. Inches	Internal. Inches	External. Square Inches	Internal. Square Inches	Metal. Square Inches	External Surface. Feet	Internal Surface. Feet	Pounds
1/8	.405	.205	.100	1.272	.644	.129	.033	.086	9.433	18.632	.29
1/4	.540	.294	.123	1.696	.924	.229	.068	.161	7.075	12.986	.54
3/8	.675	.421	.127	2.121	1.323	.358	.139	.219	5.657	9.070	.74
1/2	.840	.542	.149	2.639	1.703	.554	.231	.323	4.547	7.046	1.09
3/4	1.050	.736	.157	3.299	2.312	.866	.452	.414	3.637	5.109	1.39
1	1.315	.951	.182	4.131	2.988	1.358	.710	.648	2.904	4.016	2.17
1 1/4	1.660	1.272	.194	5.215	3.996	2.164	1.271	.893	2.301	3.003	3.00
1 1/2	1.900	1.494	.203	5.969	4.694	2.835	1.753	1.082	2.010	2.556	3.63
2	2.375	1.933	.221	7.461	6.073	4.430	2.935	1.495	1.608	1.975	5.02
2 1/2	2.875	2.315	.280	9.032	7.273	6.492	4.209	2.283	1.328	1.649	7.67
3	3.500	2.892	.304	10.996	9.085	9.621	6.569	3.052	1.091	1.328	10.25
3 1/2	4.000	3.358	.321	12.566	10.549	12.566	8.856	3.710	.955	1.137	12.47
4	4.500	3.818	.341	14.137	11.995	15.904	11.449	4.455	.849	1.000	14.97
5	5.563	4.813	.375	17.477	15.120	24.306	18.193	6.120	.687	.793	20.54
6	6.625	5.750	.437	20.813	18.064	34.472	25.967	8.505	.577	.664	28.58

TABLE III

STANDARD DIMENSIONS OF DOUBLE EXTRA-STRONG WROUGHT-IRON PIPE

Diameter				Circumference		Transverse Areas			Length of Pipe Per Square Foot of		
Nominal Internal. Inches	Actual External. Inches	Approximate Internal. Inches	Thickness. Inches	External. Inches	Internal. Inches	External. Square Inches	Internal. Square Inches	Metal. Square Inches	External Surface. Feet	Internal Surface. Feet	Nominal Weight Per Foot. Pounds
1/2	.840	.244	.298	2.639	.766	.554	.047	.507	4.547	15.667	1.70
3/4	1.050	.422	.314	3.299	1.326	.866	.139	.727	3.637	9.049	2.44
1	1.315	.587	.364	4.131	1.844	1.358	.271	1.087	2.904	6.508	3.65
1 1/4	1.660	.885	.388	5.215	2.780	2.164	.615	1.549	2.304	4.317	5.20
1 1/2	1.900	1.088	.406	5.969	3.418	2.835	.930	1.905	2.010	3.511	6.40
2	2.375	1.491	.442	7.461	4.684	4.430	1.744	2.686	1.608	2.561	9.02
2 1/2	2.875	1.755	.560	9.032	5.513	6.492	2.419	4.073	1.328	2.176	13.68
3	3.500	2.284	.608	10.996	7.175	9.621	4.097	5.524	1.091	1.672	18.56
3 1/2	4.000	2.716	.642	12.566	8.533	12.566	5.794	6.772	.955	1.406	22.75
4	4.500	3.136	.682	14.137	9.852	15.904	7.724	8.180	.849	1.217	27.48
5	5.563	4.063	.750	17.477	12.764	24.306	12.965	11.340	.687	.940	38.12
6	6.625	4.875	.875	20.813	15.315	34.472	18.666	15.806	.577	.784	53.11

pipe. Double extra-strong pipe is always shipped without threads and couplings unless otherwise ordered. Its sizes and weights are given in Table III.

BOILER TUBES

6. Boiler tubes, sometimes called **outside-diameter pipes,** are usually made of charcoal iron; they are lap-welded and have a high tensile strength coupled with a ductility that enables the ends of the tubes to be expanded into the boiler plates, such as the crown sheets and tube sheets, and beaded over. Steel boiler tubes are made to the same dimensions; formerly the wrought-iron tubes gave better results, as the average steel tube was liable to contain carbon patches that soon rusted and thus caused the tubes to pit, especially if vegetable oils were used for the lubrication of engines whose water of condensation is used for feeding the boiler. To-day, however, due to improved processes of manufacture, solid-drawn seamless steel boiler tubes are decidedly superior to wrought-iron boiler tubes, possessing just as much ductility and having greater tensile strength. The sizes of boiler tubes are given in Table IV. For locomotive work, boiler tubes are made one gauge heavier than given in the table.

7. Lap-welded **semisteel tubes** are manufactured expressly for locomotive work, and hence need not be considered here.

GALVANIZED-IRON PIPE

8. The **galvanized-iron pipe** used in steam heating in the smaller sizes is the regular standard wrought-iron pipe coated inside and outside with a covering of zinc in an electric bath. It has the same dimensions as standard black pipe. Galvanized pipe is sometimes used in steam-fitting work for exhaust and vapor pipes, drip pipes, etc. exposed to the outer atmosphere. It is also used in underground

TABLE IV

STANDARD LAP-WELDED CHARCOAL-IRON BOILER TUBES

Diameter		Thickness.	Circumference		Transverse Areas			Length of Tube Per Square Foot of		Nominal Weight Per Foot.
External. Inches	Internal. Inches	Inches	External. Inches	Internal. Inches	External. Square Inches	Internal. Square Inches	Metal. Square Inches	External Surface. Feet	Internal Surface. Feet	Pounds
1	.856	.095	3.142	2.689	.785	.575	.210	3.819	4.462	.90
1¼	1.106	.095	3.927	3.475	1.227	.961	.266	3.056	3.453	1.15
1½	1.334	.095	4.712	4.191	1.767	1.398	.369	2.547	2.863	1.40
1¾	1.560	.095	5.498	4.901	2.405	1.911	.494	2.183	2.448	1.66
2	1.810	.095	6.283	5.686	3.142	2.573	.569	1.909	2.110	1.91
2¼	2.060	.095	7.069	6.472	3.976	3.333	.643	1.698	1.854	2.16
2½	2.282	.109	7.854	7.169	4.909	4.090	.819	1.528	1.674	2.75
2¾	2.532	.109	8.639	7.954	5.940	5.035	.905	1.389	1.509	3.04
3	2.782	.109	9.425	8.740	7.069	6.079	.990	1.273	1.373	3.33
3¼	3.010	.120	10.210	9.456	8.296	7.116	1.180	1.175	1.260	3.96
3½	3.260	.120	10.996	10.241	9.621	8.347	1.274	1.091	1.172	4.28
3¾	3.510	.120	11.781	11.027	11.045	9.676	1.369	1.018	1.088	4.60
4	3.732	.134	12.566	11.724	12.566	10.939	1.627	.955	1.024	5.47

work where the ground is moist, the coating of zinc preventing rapid rusting. The larger sizes, where but little pressure is carried, are made of a lighter and cheaper material, such as galvanized sheet iron built in the form of pipe.

SPIRAL RIVETED PIPE

9. The **spiral riveted pipe** is made of sheets of black wrought iron, of certain wire-gauge thickness, split up into ribbons or narrow strips, and passed over a system of rollers that roll it into the required shape, which is shown in Fig. 1.

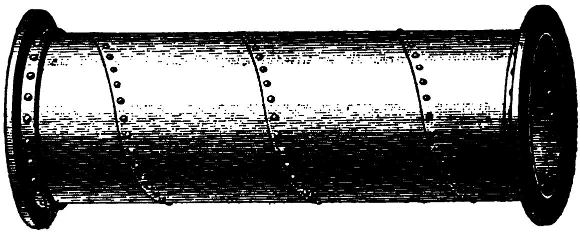


FIG. 1

The edges lapping over each other are riveted together by a riveting machine over a mandrel. The lengths must be made to measure, and are fitted at the ends with cast-iron flanges, drilled to suit other flanges, or a templet. The sections can thus be bolted together. The pipe is placed in an electric bath, and a coating of zinc deposited over it, which makes the riveted joint absolutely tight. The sizes are given in Table V.

The safe-working pressure of this pipe is considered to be one-third of the bursting pressure. These pipes are tested to a pressure of 150 pounds per square inch. They are furnished in lengths to order up to 20 feet.

The thicknesses represented by the Birmingham wire-gauge numbers appearing in Table V are as follows: No. 20, .035 inch; No. 18, .049 inch; No. 16, .065 inch; No. 14, .083 inch; No. 12, .109 inch.

TABLE V

SPIRAL-RIVETED FLANGED PRESSURE PIPE, DOUBLE GALVANIZED

Size. Inches	Diameter of Flanges. Inches	Thickness, B. W. G.	Weight Including Flanges Per Foot. Pounds	Bursting Pressure Per Square Inch. Pounds
3	6	No. 20	$2\frac{1}{4}$	900
4	7	No. 20	3	700
5	8	No. 20	4	550
6	9	No. 18	5	700
7	10	No. 18	6	600
8	11	No. 18	7	500
9	13	No. 18	8	450
10	14	No. 16	11	500
11	15	No. 16	12	450
12	16	No. 16	14	400
13	17	No. 16	15	380
14	18	No. 14	20	470
15	19	No. 14	22	450
16	$21\frac{1}{4}$	No. 14	24	400
18	$23\frac{1}{4}$	No. 14	29	370
20	$25\frac{1}{8}$	No. 14	34	325
22	$28\frac{1}{4}$	No. 12	40	365
24	30	No. 12	50	335

FLANGED WROUGHT-IRON PIPE

10. Flanged wrought-iron pipe can be made with forged flanges welded on, as shown by the end view and section in Fig. 2. The lengths are made to suit conditions. As screw joints cut into the pipe and thus reduce the

strength, the pipe with forged flanges will stand a greater pressure and hence can be lighter in weight for the same pressure than ordinary pipe. By the use of these welded flanges, a large amount of the hand labor in erecting can be saved. Table VI, known as the Master Steam-Fitters' Standard, is adopted for these flanges. The letters *A*, *B*, *C*, *D*, and *E* heading the first five columns relate to the dimensions shown by the same letters in Fig. 2.

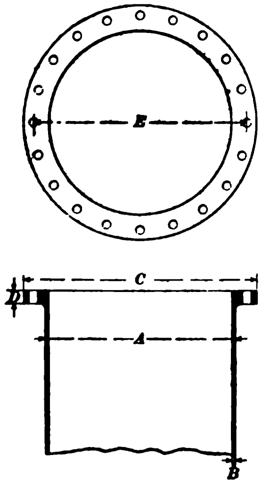


FIG. 2

11. Pipe up to 16 inches can be fitted with flanges screwed on, but above 16 inches the flanges are usually fastened to the pipe by rivets passing through a boss of the flange, as in Fig. 1. Sometimes the flange is fastened by expanding and peening the pipe into a recess formed in the flange.

CAST-IRON PIPE

12. In some manufacturing plants it is advisable to use cast iron instead of wrought iron for main steam pipes and branches, especially where acids are used, or where the pipes

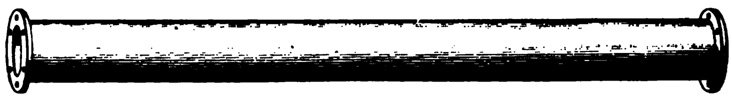


FIG. 3

must be placed unprotected in the ground. It is also good practice to use cast iron for return mains where water is used that contains sulphur or any other substance tending to rapidly corrode wrought iron. A length of cast-iron pipe

TABLE VI

MASTER STEAM-FITTERS' STANDARD FOR WELDED FLANGES

A	*B*	*C*	*D*	*E*	Number of Bolts	Size of Bolts	Weight of Pair of Flanges Finished. Pounds
$6\frac{5}{8}$	$\frac{1}{4}$	11	$1\frac{1}{8}$	$9\frac{1}{2}$	8	$\frac{5}{8}$	45
$7\frac{5}{8}$	$\frac{5}{16}$	$12\frac{1}{2}$	$1\frac{3}{16}$	$10\frac{3}{4}$	8	$\frac{5}{8}$	56
8	$\frac{5}{16}$	13	$1\frac{3}{16}$	$11\frac{1}{4}$	8	$\frac{5}{8}$	58
$8\frac{5}{8}$	$\frac{5}{16}$	$13\frac{1}{2}$	$1\frac{3}{16}$	$11\frac{3}{4}$	8	$\frac{3}{4}$	60
$9\frac{5}{8}$	$\frac{5}{16}$	15	$1\frac{3}{16}$	$13\frac{1}{4}$	12	$\frac{3}{4}$	73
10	$\frac{3}{8}$	$15\frac{1}{2}$	$1\frac{1}{4}$	$13\frac{1}{2}$	12	$\frac{3}{4}$	78
$10\frac{3}{4}$	$\frac{3}{8}$	16	$1\frac{1}{4}$	$14\frac{1}{4}$	12	$\frac{3}{4}$	85
12	$\frac{3}{8}$	18	$1\frac{1}{4}$	$15\frac{1}{2}$	12	$\frac{7}{8}$	98
$12\frac{3}{4}$	$\frac{3}{8}$	19	$1\frac{1}{4}$	17	12	$\frac{7}{8}$	108
14	$\frac{3}{8}$	21	$1\frac{3}{8}$	$18\frac{3}{4}$	12	$\frac{7}{8}$	148
15	$\frac{3}{8}$	$22\frac{1}{4}$	$1\frac{3}{8}$	20	16	$\frac{7}{8}$	162
16	$\frac{3}{8}$	$23\frac{1}{2}$	$1\frac{7}{16}$	$21\frac{1}{4}$	16	$\frac{7}{8}$	195
18	$\frac{3}{8}$	25	$1\frac{9}{16}$	$22\frac{3}{4}$	16	1	207
20	$\frac{3}{8}$	$27\frac{1}{2}$	$1\frac{11}{16}$	25	20	1	275
22	$\frac{3}{8}$	$29\frac{1}{2}$	$1\frac{7}{8}$	$27\frac{1}{4}$	20	1	320
24	$\frac{7}{16}$	32	2	$29\frac{1}{2}$	20	$1\frac{1}{8}$	400
26	$\frac{7}{16}$	$34\frac{1}{4}$	2	$31\frac{3}{4}$	24	$1\frac{1}{8}$	440
28	$\frac{7}{16}$	$36\frac{1}{2}$	$2\frac{1}{8}$	34	28	$1\frac{1}{8}$	510
30	$\frac{7}{16}$	$38\frac{3}{4}$	$2\frac{1}{8}$	36	28	$1\frac{1}{8}$	560

is shown in Fig. 3. The usual method of connecting cast-iron pipes is by flange joints having a fibrous packing between the flanges. Flange joints should be fitted in such a manner that the only stress the pipe is subjected to will be the tensile stress due to the steam pressure. The standard sizes are given in Table VII.

TABLE VII

SIZES AND WEIGHTS OF CAST-IRON FLANGED PIPE

Bore in Inches	Thickness of Metal in Inches								
	1/4	3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
	Weight Per Foot in Pounds								
2	5.52	8.74	12.27	16.11	20.25	24.70	29.45	34.52	39.88
2 1/2	6.75	10.58	14.73	19.18	23.95	28.99	34.36	40.04	46.02
3	7.93	12.43	17.18	22.24	27.61	22.29	39.27	45.56	52.16
3 1/2	9.20	14.27	19.64	25.31	31.29	37.58	44.18	51.08	58.29
4	10.43	16.11	22.09	28.38	34.98	41.88	49.09	56.60	64.43
4 1/2	11.66	17.95	24.54	31.45	38.66	46.18	54.00	62.13	70.56
5	12.89	19.79	27.00	34.52	42.34	50.47	58.91	67.65	76.70
5 1/2	14.11	21.63	29.45	37.58	46.02	54.76	63.81	73.17	82.84
6	15.34	23.47	31.91	40.65	49.70	59.06	68.72	78.69	88.97
7	17.79	27.15	36.82	46.79	57.06	67.65	78.54	89.74	101.24
8	20.25	30.83	41.72	52.92	64.43	76.24	88.36	100.78	113.52
9	22.70	34.52	46.63	59.06	71.79	84.83	98.18	111.83	125.79
10	25.16	38.20	51.54	65.19	79.15	93.42	107.99	122.87	138.06
11	27.61	41.88	56.45	71.33	86.52	102.01	117.81	133.92	150.33
12	30.07	46.56	61.36	77.47	93.88	110.60	127.63	144.96	162.60
13	32.52	49.24	66.27	83.60	101.24	119.19	137.45	156.01	174.87
14	34.98	52.92	71.18	89.74	108.61	127.78	147.26	167.05	187.15
15		56.60	76.09	95.87	115.97	136.37	157.08	178.10	199 42

BRASS AND COPPER PIPE

BRASS PIPE

13. For steam-heating work, **brass pipe** is made in all standard iron-pipe sizes up to 6 inches in diameter. It has a thickness nearly equal to that of standard wrought-iron pipe, and hence is of sufficient thickness to be threaded the same. The regular standard lengths are 12 feet; they come without threads. Brass pipe is used chiefly for boiler connections where a pipe with more flexibility than iron is

required, and for boiler feedpipes and blow-off pipes, as brass is not so liable as iron to deteriorate under the high temperature in the flue space and smoke chambers of a boiler. Brass pipe is also used for steam coils in water tanks, or water coils in steam tanks for heating feedwater for boilers, etc. Small sizes of brass pipe are used for oil connections in machinery, as they can be easily and neatly bent, and when polished make a neat appearance. The standard sizes are given in the following table:

TABLE VIII

SIZES AND WEIGHTS OF IRON-PIPE SIZE OF BRASS AND COPPER STEAM TUBES

Size of Tube	Inside Diameter. Inches	Outside Diameter. Inches	Length. Feet	Approximate Weight Per Foot	
				Brass	Copper
$\frac{1}{8}$-inch.......	.27	$\frac{13}{32}$	12	.30	.31
$\frac{1}{4}$-inch.......	.36	$\frac{9}{16}$	12	.43	.45
$\frac{3}{8}$-inch.......	.49	$\frac{11}{16}$	12	.58	.61
$\frac{1}{2}$-inch.......	.62	$\frac{13}{16}$	12	.80	.84
$\frac{3}{4}$-inch.......	.82	$1\frac{1}{16}$	12	1.17	1.23
1 -inch.......	1.04	$1\frac{5}{16}$	12	1.67	1.75
$1\frac{1}{4}$-inch......	1.38	$1\frac{5}{8}$	12	2.42	2.54
$1\frac{1}{2}$-inch.......	1.61	$1\frac{7}{8}$	12	2.92	3.07
2 -inch.......	2.06	$2\frac{3}{8}$	12	4.17	4.38
$2\frac{1}{2}$-inch.......	2.46	$2\frac{7}{8}$	12	5.00	5.25
3 -inch.......	3.06	$3\frac{1}{2}$	12	8.00	8.40
$3\frac{1}{2}$-inch.......	3.50	4	12	10.00	10.50
4 -inch.......	4.02	$4\frac{1}{2}$	12	12.00	12.00
5 -inch.......	5.04	5.56	8 to 10	15.93	17.30
6 -inch.......	6.06	6.66	6 to 8	20.69	22.38

COPPER PIPE

14. Copper pipe can be had in the same dimensions as the brass pipe referred to in Table VIII, but is generally made only to order. The smaller sizes of copper pipe are

used for the same purpose as brass pipe; that is, for feed-water heaters, drip pipes, boiler connections, etc.

Seamless copper pipe of the iron-pipe sizes can be used for spring bends for main steam lines; sizes less than 4 inch can be bent cold. In steamship work, copper tubing for connecting the boilers and engines is generally made from sheet copper, with the seams dovetailed and then brazed. The ends of such tubes are provided with flanges brazed and riveted on; the sections are then bolted together in position. As the beating of the copper sheet draws the copper lighter in some parts than others, tubes thus made are not so well adapted for very high pressures as the seamless tubes.

FLEXIBLE METALLIC TUBING

15. A peculiar form of tubing consists of a strip of metal, formed by a special machine over a mandrel, with a curved edge on one side that laps into the curved edge of the opposite side of the same strip, the spiral seam acting as a wedge to press the two interlocking edges tightly on each other. By the ingenious method in which the pipe is made, it becomes flexible and yet remains steam-tight.

16. Fig. 4 shows a flexible metallic tube *a* in section. It is connected to a coupling *b*, which may be screwed to an iron pipe. To connect the tube and coupling, the coupling ring *c* is slipped over the end of the tubing *a*, and then the gland *d* is screwed over the tubing. Next, some asbestos-thread packing is wrapped around the tubing

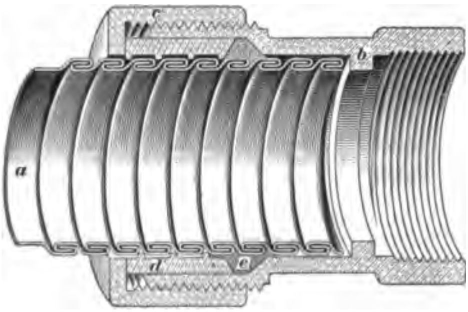


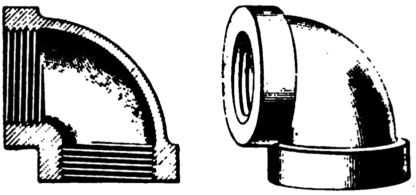
FIG. 4

at *e*; the end of the tubing is then pushed into *b*, as shown, and the ring *c* is screwed over *b* until the packing at *e* is tightly compressed. Care must be taken, however, not to twist the tubing, as then it may leak. A little clear space must be allowed at the end of the tubing, as shown.

PIPE FITTINGS

ELBOWS

17. **Elbows** are fittings that are used to change the direction of a pipe. They are made with right-hand threads and also with left-hand threads; also, with one thread right hand and the other thread left hand. The term **ell** is a trade abbreviation for elbow. The **right-angle elbow,** also called **quarter elbow,** is used for making right-angle, or 90°, turns in continuous lengths of piping. Fig. 5 shows, in section at (*a*) and in perspective at (*b*), a common cast-iron quarter elbow. It will be observed that the tapped openings are reenforced with an extra amount of metal around the threads. This extra metal is required to prevent the fitting from being split when a pipe is being screwed into it. All cast-iron fittings are provided with a reenforcement.



(*a*) (*b*)

Fig. 5

18. Elbows with left-hand threads, commonly called **left-hand elbows,** are used in places where fittings cannot be turned, as occurs in connecting up the last fitting of a loop.

19. Fig. 6 shows a **right-and-left-quarter elbow,** where, as a distinguishing mark, the left-hand end has ribs cast on it, as shown at *a*. Some manufacturers, however, indicate the left-hand thread by the letter *L* marked on the fitting.

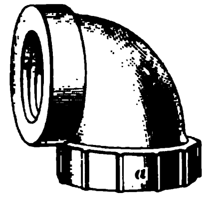


FIG. 6

20. Reducing elbows, one of which is shown in Fig. 7, are used for the same purpose as **straight elbows,** which are tapped the same size at both outlets; they differ from straight elbows in that the outlet end is tapped (threaded) for a smaller pipe. There are no right-and-left threaded reducing elbows manufactured; if required, they must be made to order. In fact, all reducing fittings are made with right-hand threads.

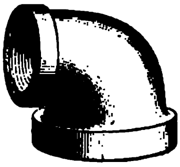


FIG. 7

21. Eighth, or 45°, elbows are intended to change the direction in which the pipe runs 45°. Eighth elbows are at present only made with right-hand threads, and are not made in reducing sizes. They should be used in preference to 90° elbows when possible. A 45° elbow is shown in Fig. 8.

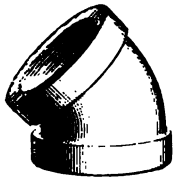


FIG. 8

22. A **side-outlet elbow,** or **three-way elbow,** which has three outlets, is shown in Fig. 9. It is seldom used, because it makes it difficult to properly allow for expansion and contraction of the pipes; but there are some cases where it is necessary. For instance, they may be used for a drip pipe to drain the water of condensation from long runs of pipe at a bend; such a drip pipe or relief should be fitted so that expansion and contraction are provided for as fully as possible. Side-outlet elbows, while listed in most catalogues, are seldom kept in stock.


FIG. 9

23. Street elbows are used in steam-fitting work only in places where the connection must be made too close to use the regular form of elbow and a short piece of pipe. The name is derived from the use to which they are put by plumbers and gas-fitters, being used by them to connect water and gas pipes to openings tapped in the street mains. They are sometimes used by boiler makers in making a close right-angle connection to the shell of a boiler or a tank, and by steam fitters in connecting feed-pipes where space is limited between the boiler and brick-work, etc. They are also called male and female elbows, the female part *b*, Fig. 10, having a thread into which a pipe can be fitted and the male part being the outer threaded end shown at *a*. Street elbows are usually made of malleable iron; nearly all malleable-iron fittings are reenforced by a round bead, shown at *b*.

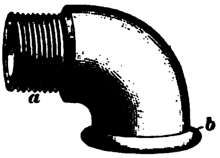


FIG. 10

TEES

PURPOSE AND DESIGNATION

24. In **tees**, as the name implies, the three connecting outlets form a T. These fittings are made in various forms and are used to take a branch pipe from a line of pipe at right angles without changing the direction of the continuous pipe. Any number of branches may be taken from a main line by screwing tees on the line. Tees are all made with right-hand threads and can be had in many different forms. The method of designating the size of a tee is to first state the size of the run and then the size of the branch. By **run** is meant a line of piping entering and leaving a fitting in the same straight line. Thus, in Fig. 11,

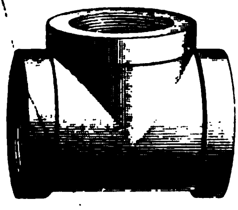


FIG. 11

if all the openings were 1-inch, it would properly be called a 1" × 1" tee. It is known more commonly to the trade, however, as a *straight 1-inch tee*. If the openings are different in size, it is necessary to be very careful in naming a tee. Thus, Fig. 12 shows a run of $1\frac{1}{2}$-inch pipe reduced to a run

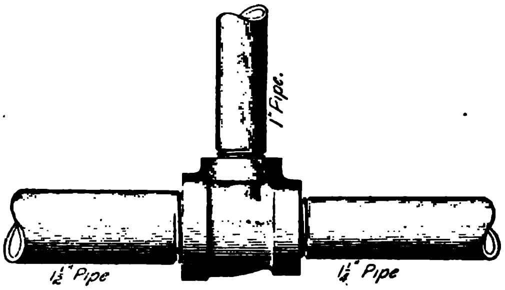


FIG. 12

of $1\frac{1}{4}$-inch pipe by a tee that has a 1-inch branch. This is known as a $1\frac{1}{2}$" × $1\frac{1}{4}$" × 1" tee. The largest size tapping on the run is always noted first; then the other tapping on the run; then the branch tapping. This simple rule, which is universally adopted, should be remembered in ordering, to prevent confusion.

25. When a tee is made so that the branch taken from the main line is smaller than the run, as shown in Fig. 13,

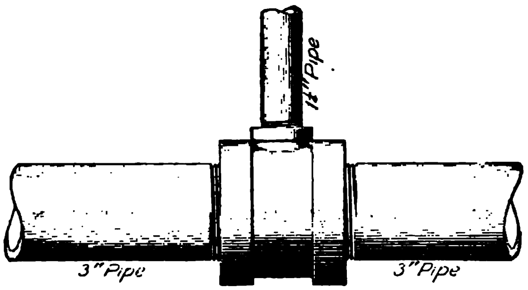


FIG. 13

the fitting is really a *reducing tee*, but it is not listed as such in manufacturers' catalogues. It is simply listed as a

tee with a reduced outlet. The tee shown in Fig. 13 is designated as a 3″ × 3″ × 1¼″ *tee.* In other words, it has a 3-inch run and a 1¼-inch outlet.

REDUCING, BULLHEAD, SIDE-OUTLET, AND ANGLE TEES

26. Reducing tees are tees that have the run reduced in size, as shown in Fig. 12. A reducing tee may also have a reducing side outlet. In designating reducing tees, the largest opening does not take precedence. The side outlet is always named last, even though it is larger than either of the others.

27. A **bullhead tee** is shown in Fig. 14. It will be observed that the run of the pipe is smaller than the outlet. It is used generally where the larger pipe must have branches both ways at an angle of 90° to it. It can be made reducing on the run, the same as is shown in Fig. 12.

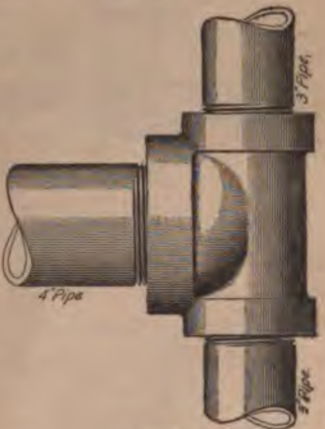


FIG. 14

28. A **side-outlet tee,** which is shown in Fig. 15, is a fitting that is listed in manufacturers' catalogues, but is very seldom used, as it is difficult to provide for free expansion and contraction of the pipes when it is employed. This fitting is usually made to order, and can be made to suit the conditions. Fittings of this kind are designated by first stating the sizes of the run and then the sizes of the side outlets. If it is desired to have a reducing tee made with side outlets, the fitting should be shown by a sketch made, as in Fig. 16, to indicate the positions of

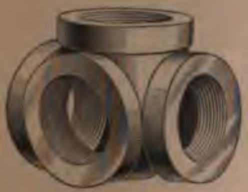


FIG. 15

the side outlets. The fitting shown in Fig. 16 (a) is designated as a $4'' \times 2\frac{1}{2}'' \times 2'' \times 1\frac{1}{2}''$ *side-outlet tee, opening looking to right.* The one shown in Fig. 16 (b) is called a $4'' \times 2\frac{1}{2}'' \times 2'' \times 1\frac{1}{2}''$ *side outlet tee, opening looking to the left.* The dotted circle in Fig. 16 (b) shows that the side outlet is on the left of the fitting, and the manufacturers would make it accordingly. From the foregoing, it will be seen that the terms right and left are applied to the side outlet in accordance with the side they are on when looking at the fitting in the direction of the run, and from the larger opening toward the smaller one.

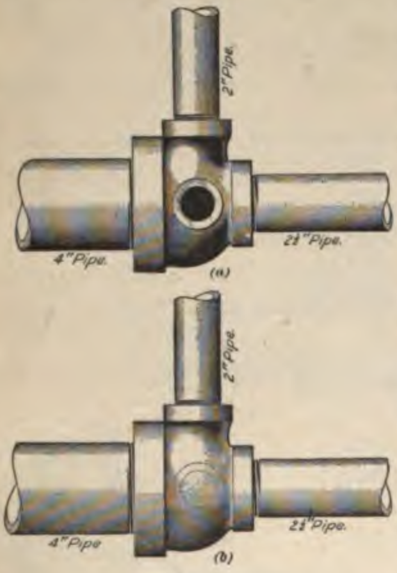


FIG. 16

29. An **angle tee,** or **Y branch,** is a fitting having an outlet that branches off at an angle of 45° to the axis of the main run. It is designated, or read, the same as a tee, except that the kind of outlet is designated by calling it a **Y**. Thus, the fitting shown in Fig. 17 is called a $4'' \times 3'' \times 3''$ *reducing* **Y** *branch.* These fittings are kept in stock in straight sizes, that is, with all outlets the same size; the reducing fittings must be made to order to suit the conditions.

FIG. 17

DIVISION TEES

30. A **division tee** is a special form of fitting used to divide the current flowing through it, so that each current will have a chance to flow without interference, or to insure that the main current will not flow past a branch without part of it being diverted into the branch. A **plain partition tee** is shown in Fig. 18; it has a straight partition *a* in the

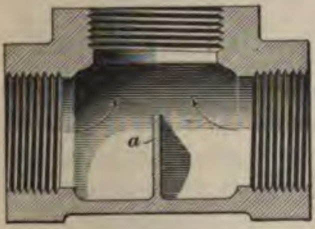


FIG. 18

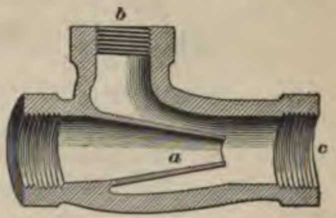


FIG. 19

middle of the fitting. This tee is used when two pipes in the same line connect to a pipe at an angle of 90°, the flow of liquid traveling toward the same branch pipe, as shown by the arrows. Fig. 19 shows a **suction tee.** This has a conical nozzle *a* extending beyond the direct line of the branch *b*, and is used to induce the branch current to flow into the run *c*.

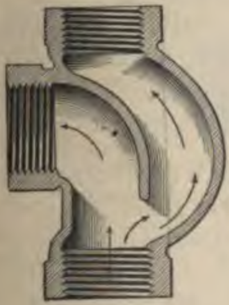


FIG. 20

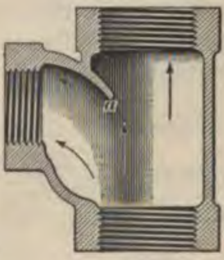


FIG. 21

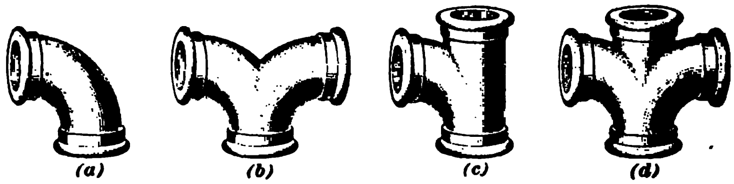
31. Fig. 20 shows the **O S fitting.** It is used to allow the branch to be favored more than the run, as in riser pipes in steam heating, when a better flow is required at the branch to a radiator on one floor than is required to supply the

radiator above it. The arrows show the direction of the currents. This fitting is used principally on vertical runs of pipe.

32. Fig. 21 shows a distributing fitting similar to Fig 20. It has a large body at the branch; the back of the fitting is straight on the run and the deflector *a* is short. This fitting is used in horizontal runs of pipe to favor the branch.

LONG-TURN FITTINGS AND CROSSES

33. **Long-turn fittings** are made similar to the standard steam fittings, but have a long bend, which allows an easy flow of the liquid. In Fig. 22 is shown a long-turn elbow in (*a*), a double-branch elbow in (*b*), a tee in (*c*), and



(a) (b) (c) (d)

FIG. 22

a cross in (*d*). The fitting in (*b*) is sometimes called a **twin elbow.** The standard makes of these fittings are all regular straight sizes; the reducing sizes are special. The double-branch elbow is similar to the bullhead tee and is very useful for branching from a main; it makes a superior connection.

34. **Crosses** are fittings used where two branches opposite each other are taken from a main run at an angle of 90° with it, as shown in Fig. 23. Although they are used extensively, their use is objectionable, as the flow from the main in two directions taken from the same point causes the current to flow unevenly, unless the branches are very well equalized. In many cases, the branch currents cut off the flow in the

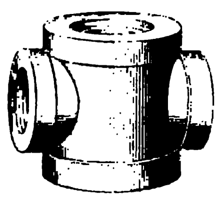


FIG. 23

run by the sharp turn made by them. There is not so much trouble in using crosses for water, as the velocity is seldom as high as the velocity with which steam flows through pipes.

NIPPLES

35. Nipples are short pieces of pipe, threaded on both ends, that are used in connecting the fittings when short connections are to be made. They are made in all sizes of pipe, kept in stock in various lengths, and are classified as *close*, *shoulder*, *short*, and *long nipples*. Nipples are made with right-hand screw threads, left-hand screw threads, and right-and-left screw threads. The left-hand nipples are very seldom used, and are generally cut to suit peculiar conditions, such as occur in coupling up two left-hand fittings, when it is not possible to get others, or where it will occasion much loss of time to get the proper fittings.

36. Fig. 24 shows a right-hand **close nipple** having a right-hand taper thread cut on each end. The nipple is short enough to allow the fittings to come close together, whence the name.

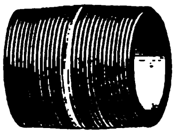


FIG. 24

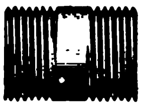


FIG. 25

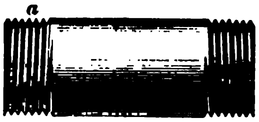


FIG. 26

37. Fig. 25 shows a right-hand **shoulder nipple.** The threads are both right hand. The short piece of unthreaded pipe in the center is called a **shoulder.**

38. Fig. 26 shows a **right-and-left short nipple.** The end *a* is threaded left hand.

39. Long nipples differ from short nipples only in length. Some people call them **short pieces of pipe.** There are no specific lengths that define a long nipple.

40. The right-hand nipple is used where it is possible to extend connections by the turning of the fitting. The right-and-left nipple is used where space will not permit the turning on of a fitting, as in connecting up to a radiator or main. As the pipe wrench is used on such a nipple, it should be made of extra-heavy pipe, to prevent its being flattened or split by the wrench. Nipples up to 2 inches can be cut with the ordinary hand tools, but the work is very slow and, hence, expensive; nipples cut by machinery can be purchased much cheaper than they can be made by hand.

41. A nipple with a hexagon center is shown in Fig. 27. It is made of malleable iron cast in the form of a sleeve. As it is used chiefly for connecting materials that cannot be turned, it is threaded right hand and left hand, as shown. It is screwed up by means of a narrow wrench, usually called a **spanner,** and applied to the hexagon center. In these nipples, both threads have the same length. They are used chiefly for connecting up sections of radiators.

FIG. 27

42. Locknut nipples, or **long screws,** are used in some cases for final connections, especially in gas work. In steam-heating work, however, they are used only in places where

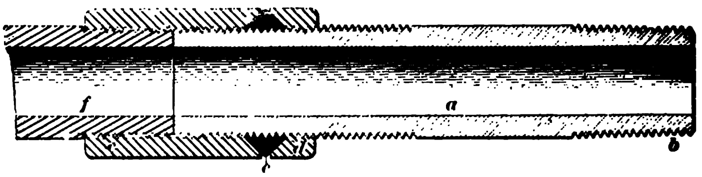


FIG. 28

the connecting pipes will not permit springing in order to make the connection. They consist of a short pipe *a*, Fig. 28, with a taper thread *b* on one end sufficiently long to make a tight screw joint in the fitting; the other end is

threaded with a straight thread somewhat longer than the coupling *c*. A short locknut *d*, also called a **follower**, made by cutting a coupling in two pieces in the lathe and turning a cup-like recess in it, is fitted to the thread. This will serve as a gland and will hold packing *e* when the follower is screwed up tight against the coupling. After the nipple *a* is screwed into the fitting and lined up for final connection, the coupling *e* is screwed up tight on the other pipe *f*. A lamp-wick or hemp gasket soaked in white lead is wound around at *e* and the follower is screwed up tight.

43. Although the long screw is shown and described here, it is not recommended for steam-heating work. Right-and-left fittings should be used instead. The long screw may be used with impunity only where the temperature of the pipes connected by it does not change much and where there is no vibration or jarring of the pipe.

44. Locknuts are used, as previously described, to make up joints on long screws, etc. They are also used on the ends of pipes to serve as supports, or to protect threads in shipping. A locknut is shown in Fig. 29. The face *a* screws against the gasket and is faced and slightly countersunk.

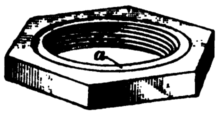


FIG. 29

COUPLINGS

45. Couplings are simply sleeves threaded inside. They are used for connecting up continuous lengths of pipe. Each length of standard pipe shipped by manufacturers is fitted with a coupling on one end, except extra-strong pipes. A common wrought-iron or steel pipe coupling is shown in Fig. 30. It is tapped right hand at both ends with taper threads.

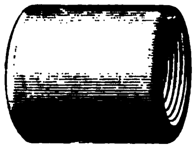


FIG. 30

46. A **reducing coupling** is shown in Fig. 31. This is usually made of cast iron in the larger sizes and of malleable iron in the smaller sizes. The coupling shown is made of cast iron. It consists of a short sleeve with a large opening and a small opening, each tapped to suit the different sizes of pipes to be connected together. An **eccentric, or offset reducing coupling**, is shown in Fig. 32. It is used to facilitate the draining of a horizontal pipe and to preserve the bottom alinement. These fittings are only made with right-hand threads.

FIG. 31

FIG. 32

47. A **right-and-left coupling** is shown in Fig. 33. It is used for coupling up pipe lengths where final joints are to be made and where the pipes cannot be turned. It consists of a sleeve tapped with a right-hand thread in one end and a left-hand thread in the other end. Different makers have different kinds of outside finish for these fittings to distinguish them from common couplings; the illustration represents a good construction. The bars a, a are the ***right*** and *left* distinguishing marks, and the beads b, b are strengthening bands, very much required on such a fitting.

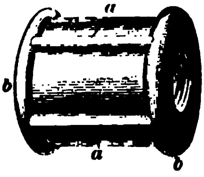


FIG. 33

48. A **solid flange** is shown in Fig. 34. This is sometimes called a **blind plate**, or **blind flange**. It is made of cast iron and is used principally for closing the ends of flanged pipes, etc. Holes are drilled to correspond with the holes in the pipe flange, and the solid flange is secured with bolts and a gasket. Plain flat flanges are generally used up to 18 inches in diameter. For larger sizes, ribbed solid flanges are used. The ribs are cast on to strengthen the flat plate.

FIG. 34

49. Fig. 35 shows a **common flange** threaded inside to receive the pipe. The bolt holes are not shown in the figure; these are usually drilled to correspond with the bolt holes of the apparatus to which the flange is intended to be bolted. Solid and common flanges can be procured in stock sizes without bolt holes.

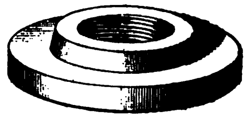


FIG. 35

BUSHINGS, PLUGS, AND CAPS

50. Bushings are fittings used to reduce an outlet in a fitting or to connect a pipe to a larger outlet. They are usually made with right-hand threads. Some of them are made with a hexagon top, as shown in Fig. 36, for convenience in screwing the bushing with a monkeywrench. Others are made without the head, as shown in Fig. 37, and are called **faced bushings**, or **flush bushings**. They can be screwed into the opening to form a neat flush finish. Some steam fitters call these bushings **thimbles**.

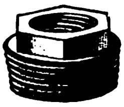


FIG. 36

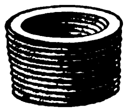


FIG. 37

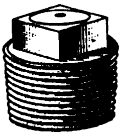


FIG. 38

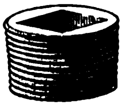


FIG. 39

51. Plugs are fittings used to close tapped openings in fittings when the openings are not required. Fig. 38 shows the common form of plug; it is provided with a projecting square head for screwing up with a wrench, and is made of cast iron. Fig. 39 shows a faced plug. It is made so that there will be no projection, and has a square depression in the face of the plug for screwing it in with a square bar or key. These plugs are usually made right hand, but left-hand plugs can be had to order.

52. A **cap** is shown in Fig. 40. It is used to close the end of a pipe, and consists of a hollow casting threaded inside. Some caps are made with a square projection on the back; others are plain, and others are hexagonal on the body. The cap shown has short ribs to allow the pipe wrench to get a good hold in screwing on the cap.

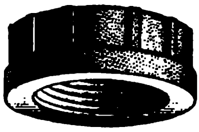


FIG. 40

UNIONS

CONSTRUCTION OF UNIONS

53. **Unions** are used for final connections in piping, and consist of three parts, namely, two sleeves threaded to screw on the ends of the pipes to be joined, and a threaded coupling ring to draw them together. Unions for steam or hot-water fitting work should have ground joints. Ordinary faced unions with washers between the faces of the parts often leak and cause trouble. It is considered the best practice to dispense with unions on small sizes of pipe, and use right and left threaded connections where possible. In very close connections, however, unions with a ground brass seat may be used, provided the pipes to be joined are not sprung to make the connection.

54. A **universal coupling,** or **union,** has a ground ball joint where the parts come together. It allows pipes to be connected at an angle.

55. **Flange unions** consist of cast plates having a threaded hole for the pipe, and are faced on one side; they are clamped tightly together by bolts, the bolt holes being either cored or drilled. Some flange unions have pockets on the outside of one flange, as shown at *a*, Fig. 41, in order to prevent the bolt from turning while the nut is being

screwed home. A projection, or boss, *b* gives sufficient length to the thread that is tapped into the opening. Flange joints are usually made steam-tight by placing a gasket of some fibrous packing between the flanges. These fittings are used in making final connections for pipe larger than 2 inches in diameter, although in some cases they are used for smaller sized pipe.

FIG. 41

56. Shrink flanges are a special kind of flange that are shrunk on the ends of pipes and riveted on instead of being screwed. They are used for large pipe connections. The end of the pipe is turned to a smooth surface a distance slightly greater than the thickness of the flange. The flange is then bored out, making the opening slightly smaller than the turned end of the pipe. The flange is now expanded by

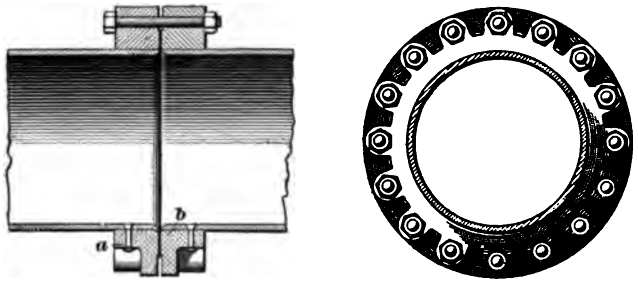


FIG. 42

being heated, and is driven over the end of the pipe; it is then allowed to cool and thus contract, or shrink, into position. Rivet holes are then drilled, and the flange is riveted to the pipe, as shown at *a*, Fig. 42. To insure a steam-tight connection, the end of the pipe is peened over a chamfer in the flange, as at *b*. The flanges are then bolted together with a gasket of packing between them.

PACKING FOR UNIONS

57. Gaskets or packing rings for steam-pipe flanges and for flange unions are made of various materials. In low-pressure heating, a heavy brown-paper gasket soaked in white lead and boiled linseed oil is sometimes used if the flanges are faced smooth and true. Such a packing is not used by the best engineers, as the different makes of asbestos and composition packings are better materials for the purpose. Where a first-class joint is required, the corrugated-copper gasket shown at *a*, Fig. 43, is reliable, as it can be made up tight without fear of compressing the material into the pipe. It will successfully resist a very high temperature. Other good forms of gasket are the **Merwarth** and the **McKim**. These consist of a flexible metal or vulcanite ring placed between copper bindings. A good gasket can be made by using fine-wire cloth and filling the meshes with red lead.

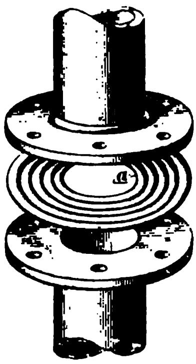


FIG. 43

58. The packings known to the trade as **Rainbow, Vulcabestos, Jenkins' 96, Usudorian,** and others belong to the vulcanized-rubber class, and are all satisfactory if used according to the manufacturer's directions.

In the asbestos class of packings are the **Monarch,** the **Hercules,** and others. Some of these packings are made with a wire framework passing through, or woven in, them.

RETURN BENDS AND MANIFOLD TEES

59. **Return bends** are used for making coils, or to make a short turn in a pipe, to return it in the same direction. They are made in various sizes and are of the *close*, *open*, and *wide* patterns; in some cases, the threads are tapped to

give a slant to the pipes. They are also made with right-hand threads in one opening and left-hand threads in the other, and can be bought with both threads left hand.

60. Fig. 44 (*a*) shows a **close return bend,** and (*b*) an **open return bend.** The right-hand-thread return bend,

(a) (b)

FIG. 44

like all other right-hand fittings, must be turned on the pipe, and sufficient allowance must be made to admit of this. The right-and-left-hand fitting is made for use where there is not room to swing the fitting, the pipe being screwed into two fittings at the same time, similar to a right-and-left nipple. **Pitched-thread** return bends, that is, return bends in which the threads are not parallel, must usually be ordered tapped to the required slant.

61. Back-outlet return bends are used chiefly in coil work, or where two coils are connected into one pipe, or two pipes running parallel are joined to one, as shown in Fig. 45.

FIG. 45

62. Manifold tees, or **headers,** are used for making flat coils, where the pipes run in the same direction and are parallel. They are made with outlets on the end for connections to the supply pipes. A common manifold, sometimes called a **branch tee,** is shown in Fig. 46. The end *a* is tapped and closed by a plug, and is said to be **blanked.** A supply pipe *b* connects to the other end.

Manifolds are also made with back outlets, as shown by dotted lines at *c*. In naming this fitting, the outlets in

multiple are first named, as *a ten-branch 1¼-inch tee by 2-inch run*, which means that there will be ten pipes 1¼ inches in diameter branching out from the manifold, and the body of the manifold, or tee, will have 2-inch tapped openings on the end. If only one outlet is required on the end, it should be ordered as follows: *One end tapped 2 inches, the other end blanked.* Manifolds for coils can be made to order to suit the work. Sometimes it is convenient to have the outlet tapped in the side, but in all cases where back or side outlets are required, they must be ordered special. The tapping is usually right hand, but other tappings can be ordered.

FIG. 46

SPECIAL FITTINGS

63. A cast-iron **offset** is shown in Fig. 47. It can be had in all sizes with an offset of 4 inches, 6 inches, or 8 inches. They are very handy fittings. The chief trouble in using offsets, however, is that they cannot be swung around when near walls, and consequently must often be connected up with right-and-left connections. This is the reason that many fitters prefer using nipples and 45° elbows instead, which are very unsightly, however.


FIG. 47

64. Offset fittings can also be had in the form of tees, crosses, couplings, etc. Fig. 48 shows an **eccentric tee.** The object of this fitting is to prevent lodging places for water in the main *a*, which is always the case where the ordinary reducing fitting placed horizontally is used.

Fig. 49 shows an **eccentric cross.** It is used chiefly for taking a supply both ways from either the top or bottom of

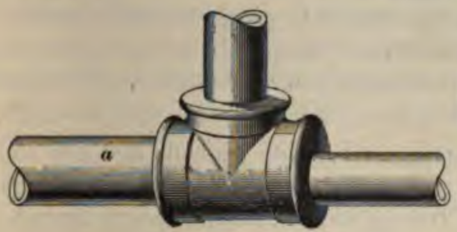
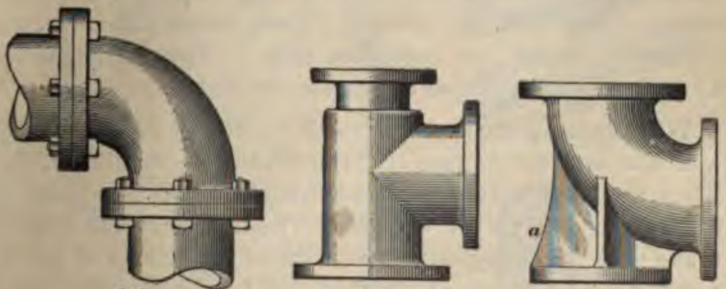


FIG. 48

FIG. 49

a main. Eccentric or offset fittings are usually made to order. Sketches showing the branches must be sent with the order.

65. Flanged cast-iron fittings have faced flanges in which the bolt holes are generally drilled to suit a standard templet to insure interchangeability. The benefit derived from using flanged fittings and pipe is that changes in, and additions to, piping can easily be made. Flanged connections are objected to by some people on account of the joints requiring packing and being liable to leak, but if proper provision is made for expansion, so that the piping is not subjected to excessive bending and twisting stresses, and if proper packing is used, the chances of leakage are small.



(a) (b) (c)

FIG. 50

66. Fig. 50 (*a*) shows a cast-iron **flanged elbow** connected to two pipes; a **reducing flanged tee** is shown in

Fig. 50 (*b*); Fig. 50 (*c*) shows a so-called **base elbow,** which has a bracket *a* with a wide base cast on it. This kind of elbow is used at the bottom of a long run of vertical pipe, the base being placed on a masonry pier, or similar suitable foundation, in order to support the weight of the pipe above it. Nearly all kinds of fittings can be bought with flanges instead of tapped ends.

67. Semisteel fittings are made special, and are usually made from special patterns, which conform somewhat to the cast-iron flange fittings and to the long-sweep threaded fittings. They are cast of a special metal having a high tensile strength.

68. The malleable-iron fittings commonly used by plumbers and gas-fitters are not adapted for use with iron pipe for steam work; they will not stand the strains due to expansion and contraction. For this purpose extra-heavy patterns are made, which are used chiefly in connecting up feedpipes and blow-off pipes in the fire-spaces of boilers.

69. There are two kinds of **brass fittings,** those made similar in pattern to malleable-iron fittings and those made similar in pattern to common cast-iron fittings. The latter are preferable for steam work. They are used extensively for feed and blow-off connections, also steam-gauge and water-gauge connections, and in places where iron pipe and fittings would rust out quickly. They are threaded for, and used with, "iron-pipe size brass pipe." These fittings can be polished or otherwise finished as desired.

70. Railing fittings are made chiefly of malleable iron and are used for fences, enclosures around machinery, etc. They are made with right-hand threads, but can be made to order with any thread desired. These fittings can also be made with reducing outlets in various reductions of one or two sizes. They can also be had cast from brass, and either in the rough (that is, as they come from the mold) or finished (that is, polished). The distinguishing feature of these fittings is that the body is spherical in form and the outlets have no beads for reenforcement.

71. Ornamental fittings are made for ornamental finish, chiefly on coils. They are made expressly for this purpose and can be obtained made of cast iron or of cast brass. In ordering these fittings, they should be described fully and the tapping specified, such as *left-hand threads* and *right-hand threads*. With the exception of the ornamentation, they are practically the same as other common fittings.

PIPE SUPPORTS

PLATES, STANDS, BRACKETS, AND SADDLES

72. Hook plates are used to support heating pipes where they are assembled in the form of coils, or other pipes that run parallel to one another. In Fig. 51 (*a*), a **single hook plate** of the common pattern is shown; a **multiple hook plate** of the same pattern is shown in Fig. 51 (*b*); a **single offset hook plate** is shown in Fig. 51 (*c*), and a **multiple offset hook plate** is shown in Fig. 51 (*d*). The ends are offset so that the pipes will be held clear of any small projections on the face of the wall. Hook plates are fastened to the walls with screws or expansion bolts. Care should be taken in ordering hook plates to state the size and number of hooks, which latter are

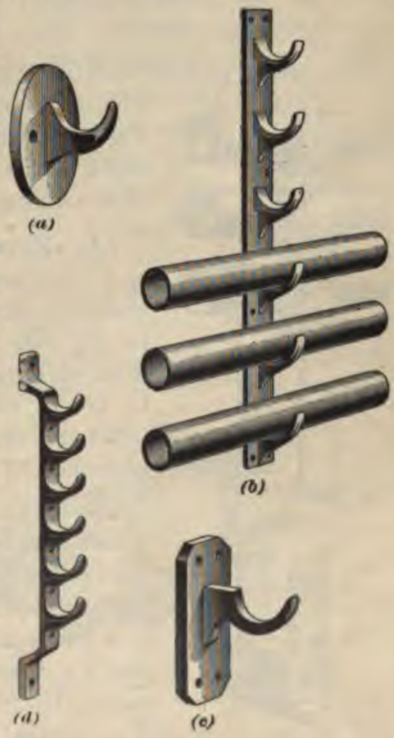


FIG. 51

generally called **branches;** thus, *one ten-branch $1\frac{1}{4}$-inch hook plate*, or *one single $1\frac{1}{4}$-inch hook plate.* If offset plates are to be used, state *one ten-branch $1\frac{1}{4}$-inch hook plate, offset ends, $1\frac{1}{2}$ inches* (or as much as required). Offset hook plates are usually made to order. Hook plates similar to those shown in Fig. 51 can be had pressed out of sheet steel.

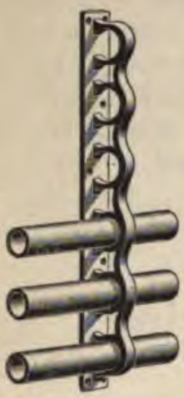


FIG. 52

FIG. 53

73. Ring plates have a ring for the pipe, as shown in Fig. 52, instead of the hook shown in Fig. 51. They are used in places where pipes would fall out if hooks were used, as at ceilings and on ships.

(a)

(b)

FIG. 54

74. Expansion plates are similar to hook plates, but instead of hooks the brackets have a flat surface, as shown in Fig. 53. They are used at the corners of long coils to allow the pipes to freely expand and contract. The brackets are made longer than the branches of hook plates.

75. There are numerous places where cast-iron hook plates cannot be used; for example, where pipe coils stand away from a wall. In such cases it is necessary to support the coils from the floor with **coil stands.** In some cases, they are made, as shown in Fig. 54 (*a*), of flat iron with the ends bent to form feet. In other cases, a

cast-iron block is made and the iron bent around the coil and bolted to the block, as shown in Fig. 54 (*b*). Each stand should be provided with a support for each pair of pipes or each separate pipe, so as to preserve the alinement. Each support should preferably have a piece of pipe, as *a*, slipped over the bolts to form a distance piece that will prevent the sides *b*, *c* from being bolted tightly against the pipes. This will allow the pipes to expand freely.

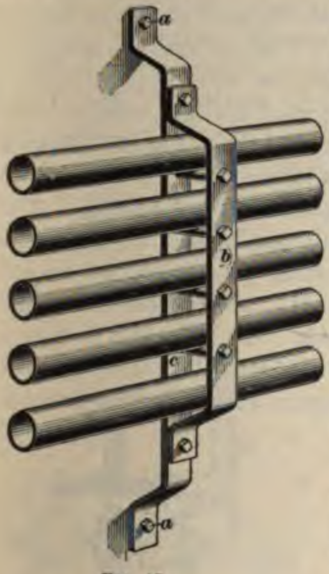


FIG. 55

76. Side-wall, or ceiling, brackets are used in many cases to make a strong and serviceable support for pipes and coils. They are forged of iron to the required shape. They are particularly suitable for supporting coils in skylights, on ceilings, or on sloping walls, where the cast-iron hook plate will not give a secure support. Fig. 55 shows such a bracket secured to a brick wall by expansion bolts at *a*, *a*. A forged iron strap or bar *b*, offset at both ends, is bolted to the bar *c*, the bolts forming the pipe supports.

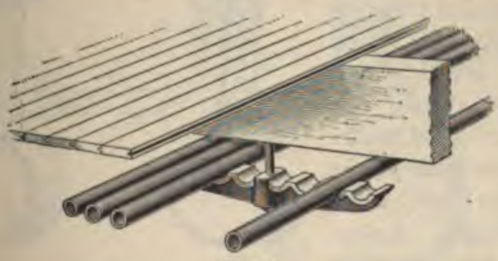


FIG. 56

77. Pipe saddles are made of cast iron; they have notches for the pipes, as shown in Fig. 56. The smaller sizes

are made with one hole at the center to admit a bolt for hanging the pipes from the ceiling, as shown in the illustration. Long saddles should have two bolts, one at each end, which make a better support. In naming these fittings, they should be designated, for example, thus, *one ten-pipe 1¼-inch saddle*, which is a saddle for ten 1¼-inch pipes.

78. Roller supports consist of rollers of cast iron having a hole for a rod to slip through. The rollers are made to suit the size of pipe coil to be used and are usually sold separately. Fig. 57 shows a roller support for four pipes attached to the ceiling. The rod that passes through the rollers is a piece of round steel. It is threaded on the ends and secured in place with locknuts. The hanger shown is secured to the ceiling beams with lagscrews, and is considered to be about the best coil support made.

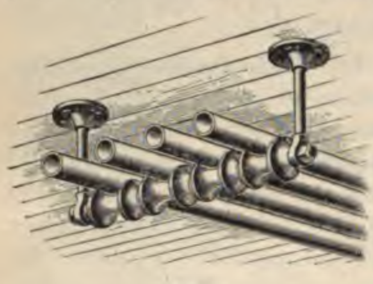


FIG. 57

PIPE HANGERS

79. There are numerous ways of hanging steam pipes, of which some are crude makeshifts that should not be found on good work. No engineer who prides himself on his work will use them. A pipe hanger should be easily adjusted after the line of pipe has been put up and alined, and should be so constructed that sections of pipe can be readily taken down.

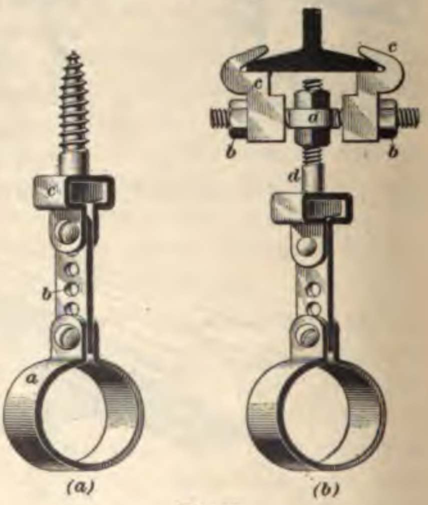


FIG. 58

80. Fig. 58 (*a*) shows the **Ideal pipe hanger.** This is a strong, although light-looking, hanger made of flat steel. The clamp *a* is sprung over the pipe and clamped to the perforated bar *b*, which in turn is clamped to a steel socket *c* enclosing a bolt or lagscrew. It can be adjusted by the flat perforated bar *b*, which is cut off to suit. A beam clamp, as shown in Fig. 58 (*b*), is used for clamping the hanger to iron and steel beams. It is made entirely of steel; the adjusting bar *a* is fitted with locknuts *b*, *b* on each end for holding the toes or hooks *c*, *c* around the beam and at the same time obtain an easy sidewise adjustment. A fine vertical adjustment is obtained by means of the bolt *d*.

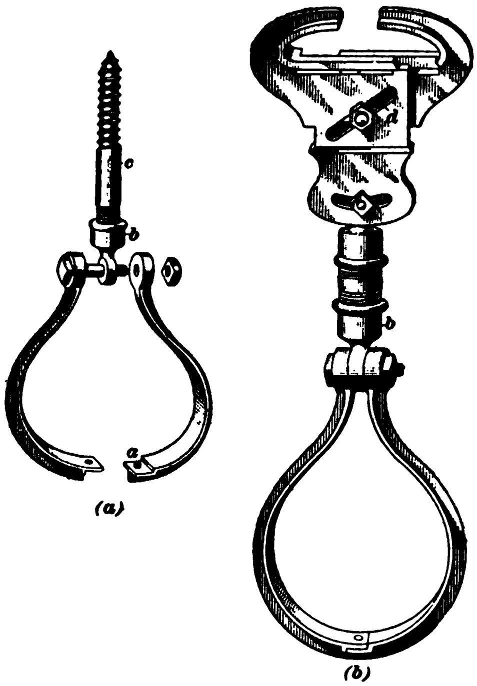


Fig. 59

81. The **Blake hanger,** shown in Fig. 59 (*a*), is made of malleable iron. Its construction somewhat resembles that of the Ideal, with the exception that the clamp is in two parts joined at the bottom with a tongue or pin, as shown at *a*. The clamp is bolted to a socket *b* that is tapped with a pipe thread and into which a lagscrew *c* is screwed. The lagscrew is used for connection to wooden beams. The Blake hanger for iron and steel beams, however, is provided with a nipple that attaches the socket *b* to an adjustable beam clamp. The beam clamp is made with a diagonal slotted hole *d* for a bolt, and allowing adjustment to the iron beam.

82. The **Universal hanger** is a cast-iron hanger, with a ring made in halves and bolted at the bottom; it has an oblong button end at the top, which connects into a box-like casting. This casting is bolted to the same style of socket and lagscrew as used in the Blake hanger. A malleable-iron beam clamp and an additional socket and nipple are used for connection to iron beams.

83. The **Hoey hanger** has a cast-iron loop in the form of a stirrup; this has a recessed top fitting over a bolthead held in place by a cap that passes over the top of the hanger. The pipe is supported on a roller made of iron pipe placed over a bolt passing through each end of the stirrup.

84. The **ball-and-socket hanger** is substantially the same as the Blake, except that the base of the lagscrew, or hanging bolt, is provided with a ball on the end. This is enclosed in a socket, one-half of which is cast on the top of each leg of the loop. The socket is held in position over the ball by a bolt and nut. One of the principal advantages of the hanger is that the pipe can be lined up, by turning the lagscrew or beam clamp hanging bolt, without uncoupling the loop around the pipe.

FLOOR PLATES, CEILING PLATES, AND SLEEVES

85. Floor and ceiling plates, sometimes called **escutcheons,** are used for making a neat finish around the pipes where they pass through partitions, floors, or walls. The styles shown are made of cast iron or cast brass. Fig. 60 (*a*) shows a simple, plain cast-iron floor plate with a bead on the outer edge and at the opening through which the pipe passes. Sometimes screw holes are drilled in the plate, as shown, so that it can be secured to the floor. Fig. 60 (*b*) shows a similar plate with a collar that passes around the pipe. It is tapped for a setscrew, which, when screwed against the pipe, prevents the plate from falling down. This is generally used as a ceiling plate. Fig. 60 (*c*) shows the **Rutzler floor plate,** for use where a one-pipe riser accompanied with a small air-vent pipe passes through the floor. Fig. 60 (*d*) shows the same floor plate for two-pipe work, when the steam and return risers are accompanied with a small air-vent pipe. In these styles of plates, the

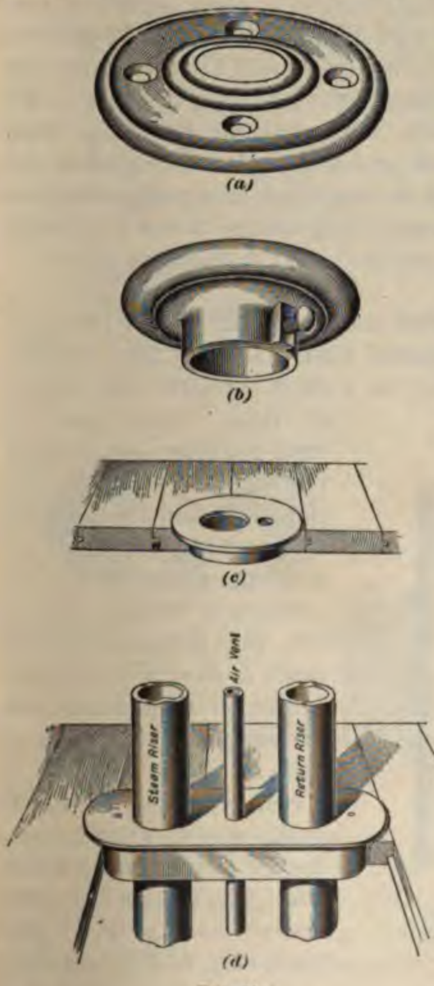
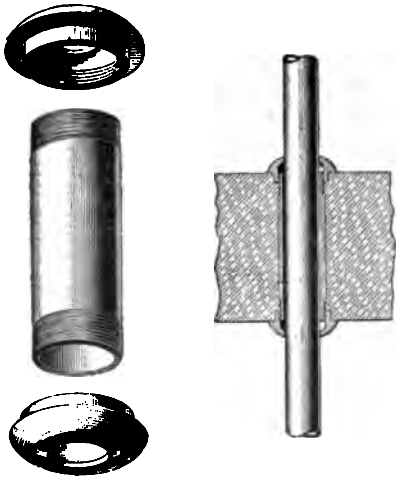


FIG. 60

small opening can be used to secure two plates, one on each side of a partition, by means of nuts and a short piece of small pipe, or an iron rod with nuts on each end.

86. If the plate shown in Fig. 60 (*b*) is used in connection with a combustible ceiling, it should have a projecting collar around the pipe at the upper opening, to prevent the pipe touching the woodwork. The plates shown in Fig. 60 (*c*) and (*d*) can also be used as ceiling plates, and may be secured in place by cleats of strap iron fastened to the bottom. The projecting flange is long enough to reach through the floor, and the straps are bent over at the floor above.

87. Screw floor plates are cast-metal plates having a recess in the bottom threaded with a regular pipe thread; they are intended to screw on a short wrought-iron nipple or tube. They can be used as floor and ceiling plates, or for walls, partitions, etc., and are the most serviceable plates and make the neatest finish for concrete or fireproof floors, etc. Screw floor plates are made of iron or brass, and can be obtained finished in various ways.



(*a*) (*b*)

FIG. 61

88. Fig. 61 shows a good screw floor plate, known as the **Hall thimble.** The three loose parts are shown in Fig. 61 (*a*), while Fig. 61 (*b*) shows the thimble in position around a steam pipe passing through a fireproof floor. The plates shown in Figs. 60 and 61 must be put in place, or at least slipped over the pipes, before the pipes are screwed up.

89. Adjustable floor and ceiling plates are also made in halves, so that they may be placed around the pipes after the work is erected. They are secured together in various ways, and when used as ceiling plates have some means of clamping them to the pipes.

90. Fig. 62 (*a*) shows the **Beaton adjustable floor plate,** while Fig. 62 (*b*) shows the corresponding ceiling plate. They are each made of two hinged halves, which when closed around the pipe are secured by a screw, as shown.

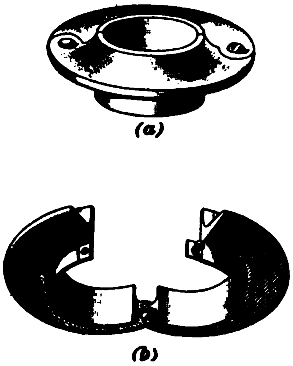


FIG. 62

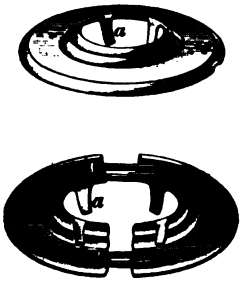


FIG. 63

91. Stamped-metal floor plates are stamped from sheet metal, and are lighter and lie closer to the floor, which is a good point in their favor. The **Russell plate,** shown in Fig. 63, belongs to this class. The parts are joined by a metal tongue projecting through a band on the adjoining half; a notch in the tongue secures the sections together. There is enough spring in the prongs *a* to hold the plate in place by their pressure against the pipe. One objection to this plate is that it has no flange around the pipe to protect the woodwork.

92. Floor and ceiling sleeves are made of tin or galvanized iron, and are used in connection with floor and

ceiling plates to insure protection against fire and to close the opening where pipes pass through floors or partitions.

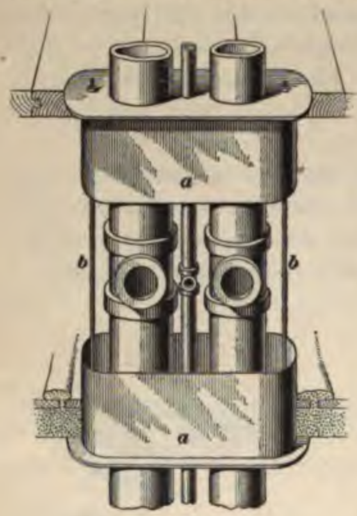


FIG. 64

93. A **double-riser sleeve** is shown in Fig. 64. It consists of two plates of the kind shown in Fig. 60 (*d*), with galvanized-iron sleeves *a*, *a* fastened to each plate. A space is left between the sleeves for taking connections from the tees shown under the floor. The sleeves can be made longer if desired, so that the pipes will be enclosed completely, one sleeve telescoping into the other. The method of securing these plates is by two small iron rods *b*, *b* with screw ends passing through both plates and having nuts.

94. Fig. 65 shows a sheet-metal **telescopic sleeve** for a single pipe. It is composed of two spun flanges, each attached to a sleeve. The lower flange is drawn up to the ceiling by cleats *a*, *a*, which are bent over and nailed to the floor, as shown. The upper flange and sleeve are pushed down in place over the lower sleeve, as shown; the upper flange is wide enough to conceal the cleats. An air space of 1 inch or more should exist between the sleeve and the steam pipe.

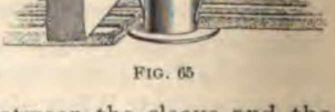


FIG. 65

95. The **Vasburg adjustable sleeve,** shown in Fig. 66, has a thread that allows the length to be adjusted and

incidentally gives stiffness. This is a strong, durable sleeve, much used for good work.

FIG. 66

96. Different localities have different laws governing the amount of space which shall be provided around the steam pipes and return pipes as a protection against possible charring of woodwork. A 1-inch air space all around the pipe is generally considered a sufficient fire-protection, and is reasonable enough to admit of connections being made without projecting the risers, etc. too far into the room.

97. In many buildings, it is advisable to place some fireproof filling in the space between the pipe and the sleeve, so that fire in one apartment cannot pass through to the one above or adjoining. Ordinary pipe covering will fit most of the tubes where made 1 inch larger than the pipe, or the space can be packed with loose asbestos in flakes, or with mineral wool.

98. A good fireproof finish can be obtained by using the **Nonparell cork riser blocks,** which consist of cork pressed under a high pressure around iron-pipe sleeves. They can be built into the walls by the masons as the building is erected.

VALVES

GLOBE VALVES

99. **Valves** are used to entirely shut off or partly check the flow of steam or water in a heating system, so that the apparatus can be properly controlled. They vary in design, some being made to completely shut off the piping, while

others are made to partially shut off the piping so as to reduce the steam pressure.

100. The most common type of valve is the **globe valve.** It is made with a globe-shaped body so as to give ample area for the passage of the fluid. Inside the valve is a partition with an opening at right angles to the valve stem. This opening has a seat either formed directly in the partition or secured to it by a screw joint. Over this opening is fitted a disk attached to a threaded spindle or stem; this passes through a hub or bonnet having a chamber around a part of the spindle to admit packing. A stuffingbox and gland, which adjusts the packing by forcing it into the stuffingbox, causing it to press tightly against the spindle, is fitted over the hub. The bonnet is placed in an opening in the body of the valve, the joint being made in some cases by a screw thread and in others by a packed flange and bolts. The disk is fitted carefully to the seat, so that the valve seat and disk form a tight joint when the spindle is screwed down. A wheel handle is generally used to screw the disk up and down.

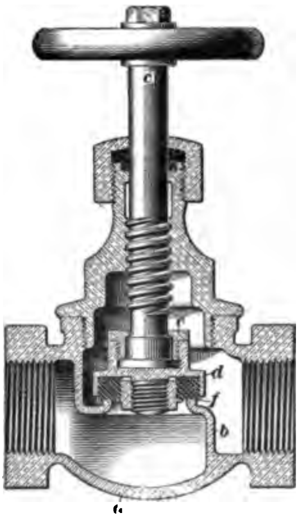


FIG. 67

101. Since the disk of a valve becomes worn by the closing and opening, and from other causes, it is often necessary to regrind it to prevent leakage. Regrinding is a tedious operation, which is done away with by using a **removable disk.** Such disks consist either of a metal casing filled with vulcanized rubber, soft metal, or hard metal, or they are fiber washers.

102. Fig. 67 shows a valve known to the trade as the **Jenkins "Diamond" valve.** This has a flat raised seat inside the body *a* of the valve and on

the partition *b*. The spindle *c* is fitted with a disk *d*, which is free to rotate and is confined longitudinally by means of a locking sleeve *e*. This disk *d* has a recess into which is inserted a composition ring *f* made of rubber and vulcanized so as to stand a high temperature. It is secured in place by a nut and washer. The disk is pliable; it fits the raised seat and makes a tight joint.

103. The **Fairbanks valve** is somewhat similar in construction to the Jenkins, except that a composition ring of asbestos and vulcanite is pressed into the recess of the disk; when renewals are required, a complete new disk can be readily inserted, as the spindle is made with a shoulder *a*, Fig. 68 (*a*), fitting into a recess open on one side and on top

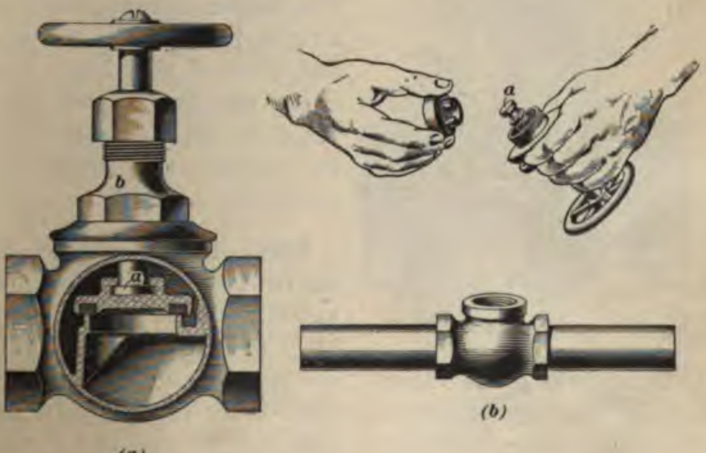


FIG. 68

of the disk, which is held in position by guides inserted in the body of the valve. This is a *quick-repairing valve*, as upon removing the hub *b* the disk can be slipped off the spindle and a new one slipped on, as shown in Fig. 68 (*b*); hence, this valve is used extensively where repairs must be made without undue loss of time.

104. The **O'Mera valve** is made similar to the Fairbanks, except that the disk has corrugations in the recess where the composition ring is placed.

105. The **Crane copper disk valve** is constructed similar to the Jenkins, with the exception that the disk is fitted with a double-faced copper ring *a*, Fig. 69, having an outer rib rounded on its face, which adjusts itself to the flat seat and forms a tight joint. The ring can be turned and used with the other edge toward the seat, should it become marred by grit or other causes. The holder is turned to form a tight joint at the top edge and sides of the copper disk. Softer metals have been used for disks of this kind, but have not proved as satisfactory as copper.

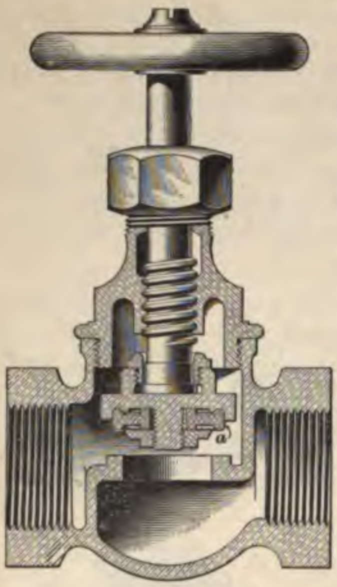


FIG. 69

106. The **Eastwood tee valve** is a type of screw-down valve having a barrel-shaped body with a partition similar to that of the globe valve. The spindle and upper section are similar in construction to that of the Jenkins valve, but the seat is made conical; the disk is of bronze and is made with a tapered and ground recess fitting over the beveled ground edge of the seat, thus forming a tight joint. The taper joint at the valve seat permits of a tighter contact between the disk and its seat than can be obtained in an ordinary flat-seated valve, assuming the same force to be applied to the spindle in each case.

107. **Iron-body valves** are made similar to **brass-body valves,** with the exception that the seat is separate ; the

seat is made of brass or hard metal secured to the iron body of the valve either by pressing it in or by a screw thread. The seat is usually faced true in place. The spindle box or hub is generally bolted to the body and packed with a gasket to form a tight joint. The stuffingbox is usually fitted with a gland having studs and nuts to compress the packing; a yoke is used to support the thread of the spindle.

108. Fig. 70 shows, in section, an iron-body flanged angle valve with a globe body. It is made with the outlet *a* at right angles to the inlet *b*. The seat *c* is placed directly in the inlet of the valve and offers less resistance to the fluid than the seat of the ordinary globe valve. It is therefore a good valve to use when the conditions will permit this; besides, it saves an elbow and sometimes a nipple, because it takes the place of an elbow. Owing to the long spindle, the disk is provided with a guide *d* that moves in a hole drilled through a spider *e* cast in one piece with the brass seat. The hole in *e* is concentric with the valve seat, and the valve disk *f* is consequently guided straight to its seat. The valve shown in Fig. 70 is intended for high-pressure work, such as 250 pounds pressure or less, and is tested to 800 pounds pressure by the manufacturer.

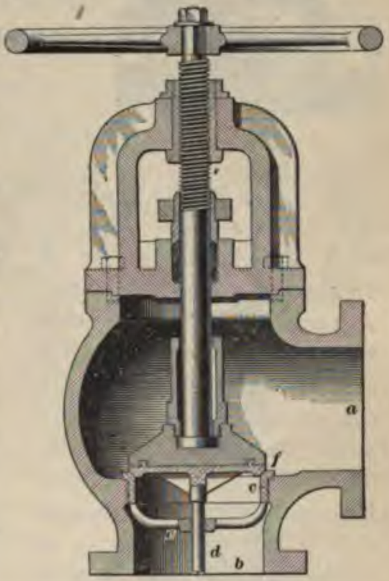


FIG. 70

109. The **Y valve,** shown in Fig. 71, is a form of valve that is similar in many respects to the globe valve, but offers less resistance to the flow of the liquid, as the seat *a*

is set at an angle of about 45° with the run of the valve. It is really midway between a globe valve and a straightway or gate valve. It is often used as a blowoff valve. This style of valve, the same as globe and angle valves, can be had with the Fairbanks, Jenkins, or other construction of disk.

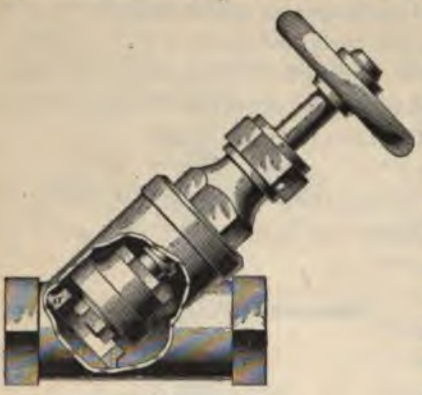


FIG. 71

110. The **packingless valve** shown in Fig. 72 is a type of valve that has lately been placed on the market. It is made in the globe and angle patterns, either with a renewable double disk or with the Jenkins type of disk with renewable ring. A peculiar feature of this valve is that the packing around the valve stem is dispensed with, and that the valve disk does not turn. The valve stem *a* is confined longitudinally by a collar *b* and a nut *c*. A seat is formed within the hub *d*, and a hard rubber washer *e* is fastened to the lower end of the collar *b* by a locknut. A brass collar *f* is ground to the upper end of the collar to form a tight joint, and is prevented from turning by two lugs entering corresponding grooves in the hub. It is thus seen that while the

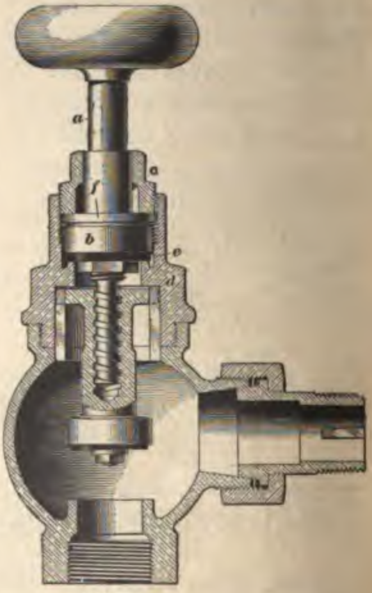


FIG. 72

valve stem is left free to turn, it is confined longitudinally, and a steam-tight joint is made. The lower end of the valve stem is threaded to fit the socket, which has the valve disk at its lower end, the socket being movable longitudinally, but prevented from turning by two opposite guides entering corresponding slots in the upper collar of the socket.

Packingless valves are very good for air-pressure or vacuum work, and are superior to the ordinary packed valves, since in the latter the joint between the valve stem and the hub is hard to make and keep air-tight.

111. All the valves shown in Figs. 67 to 72 are known as **compression,** or **screw-down, valves.**

GATE VALVES

112. **Gate valves** are straightway valves made either as **single-gate valves,** which only bear pressure on one side, and **double-gate valves,** which bear pressure on both sides. Many forms of double-gate valves are made, some of which close the opening in the run of the valve with a solid wedge; others close with a box wedge, and others with sectional gates having either parallel or wedge-shaped seats.

113. The **Jenkins gate valve,** shown in Fig. 73, has a wedge-shaped body. An inclined guide *a* at one end forces the gate, or disk, *b* to its seat *c* when the spindle is screwed down tight. The disk is loose on the spindle *d*, being made with a recess; a removable ring is secured to the disk, the same as is done in globe and angle valves. This is a single-gate valve, bearing pressure only on one side.

FIG. 73

114. The **Ludlow gate valve** is made with a solid metal disk, and is a loose disk valve, the disk being forced against the seat by a double wedge at the back of the disk. As the disk is hung from the wedge, it is lifted away from the seat on opening and hence does not slide upon the seat. When it is closed, it fits against a seat on the valve, which is at right angles to the flow of the liquid.

115. The **Chapman valve**, shown in Fig. 74, is a double-gate valve with a solid or cored disk *a* made tapering, which is machined flat on the sides and is guided by a slot *b* in each side of the disk fitting over a guide *c* at each side of the valve body; the disk seats against soft metallic rings *d*, *d*, firmly embedded at each side of the opening in the run and faced off to the same taper as the disk. The valve shown is an iron-body flanged gate valve. The lower end of the stem is threaded, and the disk travels on this thread, the stem being prevented from rising by the collar *e*.

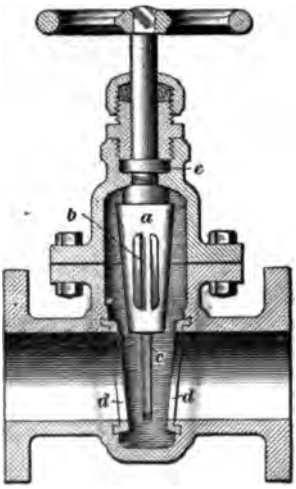


FIG. 74

116. The **Walworth gate valve** is similar in construction to the Ludlow valve, except that the seat in the body of the valve is a screwed ring faced to match the face of the disk. The **Fairbanks**, the **Kennedy**, and many other gate valves are similar in shape and general mode of operation to those described, differing only in minor details.

117. Gate valves are used where but little resistance to the flow of the liquid is desired, and therefore are largely used on water and exhaust-steam connections. When they are used for steam, however, the seats should be made of

bronze to successfully stand the high temperatures. In all gate valves, the disks rise into the upper part of the body and bonnet to allow a straight passage for the liquid. The large sizes of gate valves are usually made with a yoke and outside screw, the spindle rising in a threaded hub at the top of the yoke. The rise of the spindle in this form of valve indicates whether the valve is open or closed.

SPECIAL VALVES

118. The **elbow valve** shown in Fig. 75 is a new type of valve used chiefly for blow-off connections from boilers, but can be used for other purposes. It consists of a screw-down valve with an internally curved plug *a* having a soft-metal ring *b* around it. The spindle construction is similar to that of the ordinary valve. The plug is guided in its travel by guides, not shown; they prevent its turning and keep the curved recess of the plug in line with the outlet.

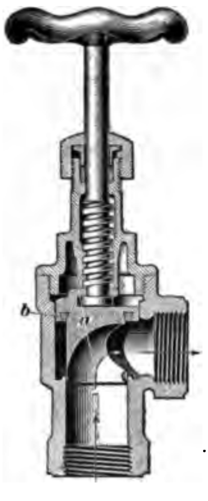


Fig. 75

119. **Tee, or cross, valves** are similar to globe valves and angle valves in construction. The valve closes off one port in the tee, the seat being placed in the inlet, like in the angle valve. They are used in some cases for mains, where a connection is brought into a main line, or for the steam-pipe connections on boilers.

RADIATOR VALVES

120. **Radiator valves** are constructed similar to globe, angle, and gate valves. To suit special conditions, they are made in different types, such as *offset globe valves*, *offset angle*

valves, *corner valves*, and *corner offset valves*. The principal distinguishing feature of radiator valves is that they are usually nickel plated, and that wooden handles are used instead of metal handles. The nickel-plated finish is applied for the sake of appearance, because radiator valves are always located in the rooms to be warmed. The wooden wheel handles are used to prevent the hands being burned in operating the valves. Radiator valves can also be had finished in plain rough brass, or with nickel-plated trimmings, or with finished and polished bodies.

121. The **angle valve** is most commonly used for a radiator, because the steam pipe *a*, Fig. 76, usually comes up through the floor and connects to the end of the radiator, as shown. The connection is usually made with a ground coupling having a hexagon nut *b*. The coupling tail *c* is screwed into the radiator tapping, and the hexagon nut screws on to the valve.

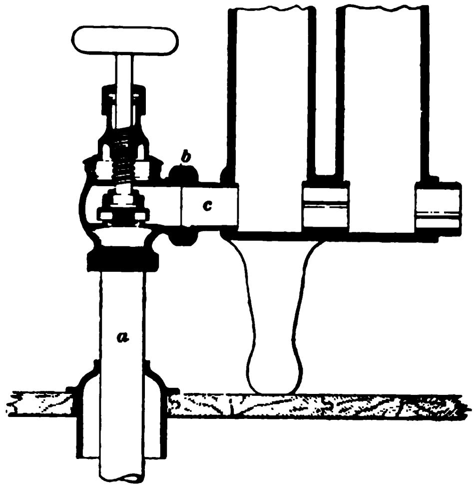


FIG. 76

122. The **corner valve** is made similar to the globe valve, except that the partition in the body is placed so as to allow the outlet of the valve to be made at the side of the globe body. Corner valves are used in places where direct connections with ordinary valves cannot be made. The offset globe valve is similar to the angle valve in general constructions, except that the outlet is in a line parallel with the inlet, but at a lower level. It is preferable to the

straightway globe valve in making radiator connections, because it admits of draining the radiator when open, which the ordinary globe valve will not do unless it is placed with the spindle horizontal.

123. An **offset corner valve** is shown in Fig. 77. It is the same in construction as the offset globe valve, except that the inlet *a* and outlet *b* are at right angles. It is really an offset angle valve with the outlet at an angle of 90° to the axis of the inlet seat at the lower level. The construction of the working parts is the same as that of any globe valve. Offset corner valves are made right hand or left hand to suit the connection in the radiator, and are listed by most makers. The corner valve with the inlet and outlet in the same plane is not made by many manufacturers.

FIG. 77

124. All the valves mentioned in the previous articles can be obtained with special key handles, and also with a shielded stem that protects the square that the key fits, so that they cannot be moved without the key. These valves are useful in schools, asylums, etc., as unauthorized persons cannot meddle with them. They are also made with a ground union joint for connecting to the radiator, as shown in Fig. 77, which makes it easy to connect and disconnect the radiator without disturbing the pipe connections.

125. The **Universal radiator valve** is a valve that has lately been placed on the market; it is the ordinary type of radiator valve of the angle pattern fitted with a ground joint union *a*, Fig. 78, on the bottom and connected to a sleeve *b*, which allows adjustment to any angle in a horizontal plane. The sleeve is made with a female thread at

the opposite end to which the piping is connected. A disadvantage of this valve is that the joint is on the pressure side, and, therefore, if the joint leaks the entire line of piping will have to be shut off before it can be reground.

FIG. 78

126. The **Collis circulating valve** is a valve by means of which a very neat and sightly job can be made of the radiator connections in a two-pipe system, as the steam and return pipes will be close together. The general construction is similar to that of the offset globe valve; the valve, as shown in Fig. 79, has an inlet *a* for the steam and an outlet *b* for the water of condensation; the nipple *c* is connected to the radiator. The condensation is carried off by a separate pipe. By using this valve, the necessity of having two valves to a radiator is done away with in two-pipe steam-heating systems, and the circulation in the heating system is not interfered with by closing the valve, which simply shuts off the steam from the radiator. At the same time the filling of the radiator with water from the return pipe is obviated, which is likely to occur when a radiator with

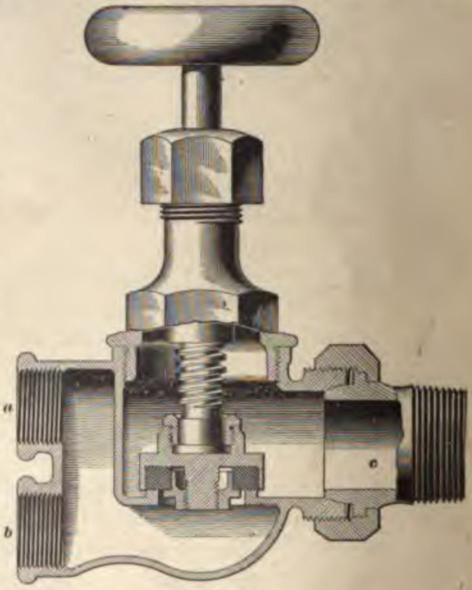


FIG. 79

separate steam and return valves is shut off by closing the steam valve only.

127. Radiator gate valves are similar to the gate valves before described, except that they have wooden wheels. The gate valve for connections to radiators admits the steam in a straight line without the resistance offered by the other types of valves, allowing the water of condensation to drain freely when used with one-pipe connection to the radiators, for which work it answers best when the connections are carried over the floor. They are finished in plain brass, or with nickeled trimmings, or nickeled all over, and in some cases are fitted with ground joint union connections.

CHECK-VALVES

128. Check-valves are valves that permit a fluid to pass through them in only one direction; they are designed so as to close automatically whenever the flow of the fluid is reversed. Check-valves are made in different forms, such as *vertical*, *horizontal*, *angle*, and *straightway*, or *swinging*, *check-valves*. The first is made with a globe-shaped body to allow a free passage for the fluid through the opening in the seat. The partition has either a tapering or a flat seat; the disk is fitted with a stem that is supported by a guide, so as to keep it in line with the seat and prevent side motion. In the large sizes having an iron body, an opening giving access to the disk is placed in the side of the body and closed with a blind flange, shown at *a* in Fig. 80. The smaller sizes are made of brass and can be taken apart like a union. The horizontal

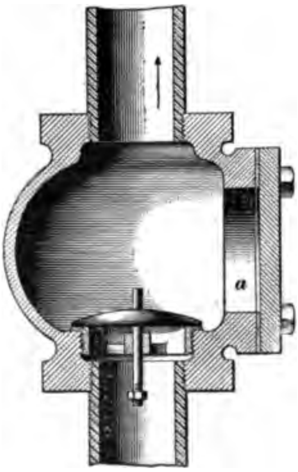


FIG. 80

check-valve has a body similar to that of a globe valve; the top opening is closed by a hollow cap forming a guide for the short stem of the valve disk, the disk being ground to the seat; sometimes the disk is fitted with a removable washer.

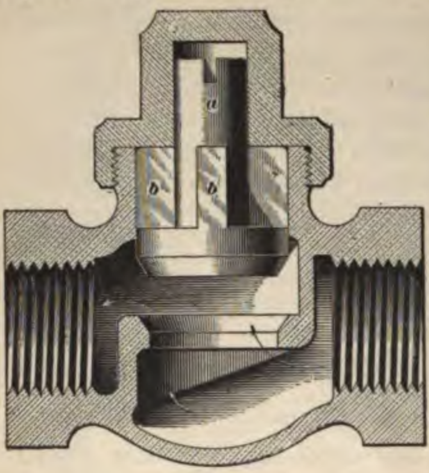


FIG. 81

Fig. 81 shows the **Powell check-valve,** whose special feature is the extension *a* to the guides *b*, *b*. Water flows through the check-valve in the direction shown, but cannot return. The angle check is similar in construction to Fig. 81, except that the body of the valve is the same as that of the ordinary angle valve, and, like the angle valve, it saves an elbow.

129. The **swing check-valve** is made different from the globe check-valve; it has a more direct water passage, and is easier to open. Fig. 82 shows the **Barnham swing check-valve.** The disk *a* is carried by a lever *b* that swings on a pivot *c*. The disk fits the lever arm loosely and is thus allowed to rotate and seat itself on the angular partition of the valve. An advantage of this form of swing check is

FIG. 82

that an ordinary mechanic can reseat the valve by unscrewing

the cap *d* and inserting a valve-facing tool. It also has a removable disk, as shown.

130. The **lock check-valve** is a straightway valve that is a combination check-valve and stop-valve. It has a swing check-valve that can be partially or entirely closed by a threaded spindle carrying a hand wheel. From this it follows that the amount of fluid passing through the valve can be regulated by means of the adjusting spindle.

131. Check-valves are very useful in steam-heating work, as they prevent a return of steam or water, which often happens when unequal pressures prevail in different pipes. They form a proper seal without offering much resistance. The best check-valves for return pipes are those that are as nearly self-draining as possible. The horizontal swing valves having a straightway passage should therefore be used. The lift check with the globe body is not suitable for such work, because the partition in the body forms a pocket or trap. Vertical check-valves are occasionally used in making vertical connections to boilers, but are not recommended, as it is very difficult to remove them when so placed. The horizontal swing checks can be used vertically, although this practice is not recommended.

STEAM-FITTING ACCESSORIES

DEVICES FOR REGULATING THE FLOW OF FLUIDS

REGULATING VALVES

BUTTERFLY VALVES

1. Butterfly valves are simple dampers that are mostly used to shut off or regulate currents of air in air pipes for blower work, or to deflect the air into other channels, but a few of these valves are used in steam work to deflect the steam into other channels. They are not steam-tight and cannot be properly regulated; therefore, they are seldom used in steam work.

BACK-PRESSURE VALVES

2. Purpose.— **Back-pressure valves** are intended to preserve a back pressure on steam engines, so that the exhaust steam can be deflected into heating systems. They are adjustable for different pressures. Back-pressure valves should offer little resistance to the flow of steam, and at the same time should be capable of relieving the pressure when more steam is discharged from an engine than can be condensed in the system; also, they should be as noiseless as possible in their operation. In order to create a back pressure on an engine, the back-pressure valve is placed in the

exhaust pipe, and the connection to the steam-heating system leaves the exhaust pipe between the back-pressure valve and the engine.

3. Back-pressure valves are made both for a horizontal and for a vertical run of exhaust pipe, and can only be used for the run for which they are designed. While each maker has a different design, all the valves operate on similar principles; they consist essentially of a valve of suitable form closing an opening to the atmosphere by a weight on the end of a lever. By changing the position of the weight, its effect on the valve, and hence the pressure at which the valve opens to the atmosphere, can be adjusted to suit the requirements of the engine and of the heating system.

4. Construction.—The simplest form of a back-pressure valve has only one seat; such a valve, known as the **Kieley single-seated back-pressure valve**, and being of the horizontal pattern, is shown in Fig. 1. It consists of a valve body similar to that of a globe valve. The valve disk *a* is held to its seat by the weight *b* on the lever *c*; this lever has its fulcrum at the standard *d* and rests on the valve stem *e*. The effect the weight has on the valve depends on the ratio between the distance from the weight to the fulcrum and the distance from the valve stem to the fulcrum;

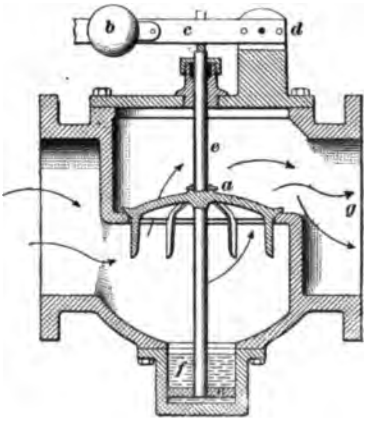


FIG. 1

in order to obtain a satisfactory range of pressures with a short length of lever and small weight, the fulcrum end of the lever and the standard have three holes each, as shown. By putting the fulcrum pin into a different hole, the distance from the valve stem to the fulcrum is changed, and hence the effect of the weight on the valve is correspondingly

altered. The exhaust pipe leading to the atmosphere is bolted to the flange *g*. The steam flows through the valve in the direction of the arrows.

Kieley back-pressure valves are fitted with a **dashpot,** to prevent the slamming of the valve in seating itself. This consists of a piston *f* attached to the valve disk and working in a cylinder. The space in the cylinder above and below the piston is filled with water; the two spaces communicate through a small hole drilled through the piston. When the valve commences to close, due to a drop in the back pressure, the water below the piston *f* can only escape slowly through the hole, and consequently the valve will seat without a shock.

5. Many back-pressure valves are made *double-seated;* they have the advantage of giving an opening equal to the area of the exhaust pipe with a smaller movement of the valve than is required with a single-seated valve, and of requiring but little force to close them. They are made for vertical and horizontal runs.

Fig. 2 shows the vertical pattern of the **Davis double-seated back-pressure valve.** The valve proper consists of two disks *a* and *b* having projections that serve to guide the disks; both disks are fastened to the same stem. The disks differ in diameter; they are held to their seats by a weight *c* on the lever *d*. As the steam pressure acts only on an area equal to the difference of the areas of the two valves, only a small weight is required to close the valve promptly. The exhaust steam enters at the bottom; on the pressure in the exhaust pipe becoming greater

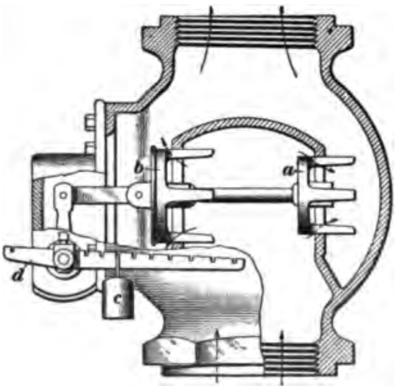


FIG. 2

than that for which the valve is set, it opens the valve and the steam passes through the two openings between the disks and their seats to the top, as shown by the arrows, and thence to the atmosphere.

6. The **Crane back-pressure valve** differs from those previously described, in that the valve proper is in the form of a hollow piston closed on one end and sliding in a cylinder. Ports are cut through the sides of the piston. When the pressure in the exhaust pipe is below that for which the valve is set, the piston is far enough inside the cylinder to close the ports. The piston is held in this position by a bell-crank lever carrying a weight on its vertical arm, which extends downwards. On the pressure rising, the steam pushes the piston upwards, and swings the bell-crank around until the ports are uncovered; as soon as the pressure drops, the weight tends to return to its lowest position, and thus closes the ports through the piston. Since this valve has no seat, there is no possibility of a slamming noise occurring when the valve closes.

7. The **Standard back-pressure valve** is similar to a swing check-valve; the valve disk is attached to a shaft to which is keyed a lever outside the valve body and carrying a movable weight, which holds the valve to its seat.

8. Back-pressure valves are also attached to the condenser of a condensing steam engine; they are then set to open at a pressure slightly in excess of that of the atmosphere. Their purpose is to prevent an overpressure in the condenser, in which case the valve opens and allows the exhaust steam to escape to the atmosphere. As these valves relieve the condenser, they are, when used for this purpose, generally called **relief valves**, and not back-pressure valves.

PRESSURE-REDUCING VALVES

9. Purpose.—**Pressure-regulating valves**, also called **pressure-reducing valves**, are used on steam-heating and power systems to maintain a low pressure in one pipe

while a high pressure is being carried in a connecting pipe. There are various ways of making valves for this purpose, depending on the use for which the valve is intended. Some of these valves are weighted, while others are loaded by springs.

10. Weighted Reducing Valves. — The **Kieley "1898" reducing valve** is designed to reduce the pressure on heating systems where a pressure but little above that of the atmosphere is required, while a high pressure is carried on the supply main for engines and pumps. This

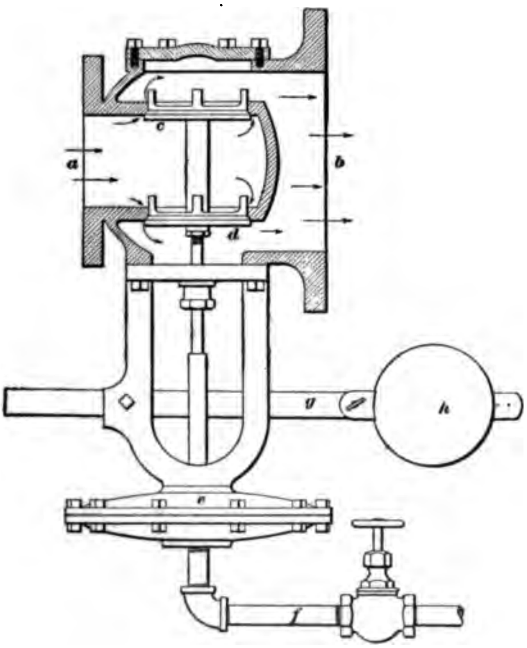


FIG. 3

valve is made with an inlet port *a*, Fig. 3, smaller than the outlet port *b*. Owing to the steam flowing into a larger space, it expands and loses in pressure, which varies inversely as the volume; a great reduction in pressure is thus obtained even when the regulating valve is wide open. The valve

itself is a double-seated balanced valve; the two disks *c* and *d* are very nearly the same size, so that a very little force closes or opens the valve. The spindle attached to the disks passes into a diaphragm chamber *e* and is connected to a large, flexible diaphragm, the bottom of which is in communication with the low-pressure main through the so-called balance pipe *f*. A weighted lever *g* passing through a slot in the spindle holds the valve open, and by shifting the weight *h* the pressure to which the steam is reduced is changed.

11. The operation is as follows: When steam is turned on, the valve is wide open at first. As the pressure rises on the side *b*, it extends through the pipe *f* to the bottom of the diaphragm, pressing the latter upwards. When the pressure has risen enough, it overcomes the effect of the weight *h* and the valve partially closes; the openings through which the steam passes to the low-pressure side are thus made smaller and the steam is *throttled*, i. e., reduced in pressure. In a few seconds the valve comes to rest in a position where the upward force on the diaphragm and the downward force due to the weight are equal. The valve retains this position until the pressure on the low-pressure side changes. Suppose it becomes less; the weight then forces the diaphragm down and hence opens the valve more, thus admitting more steam until the pressure has again risen to the point where the upward and downward forces on the diaphragm are equal.

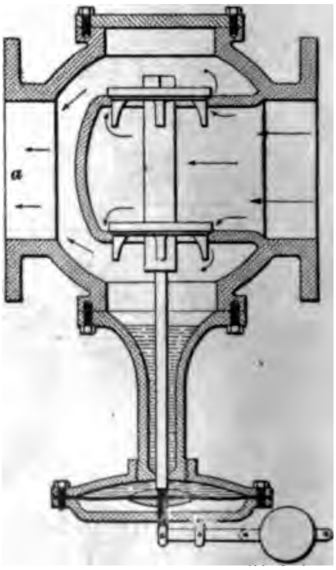
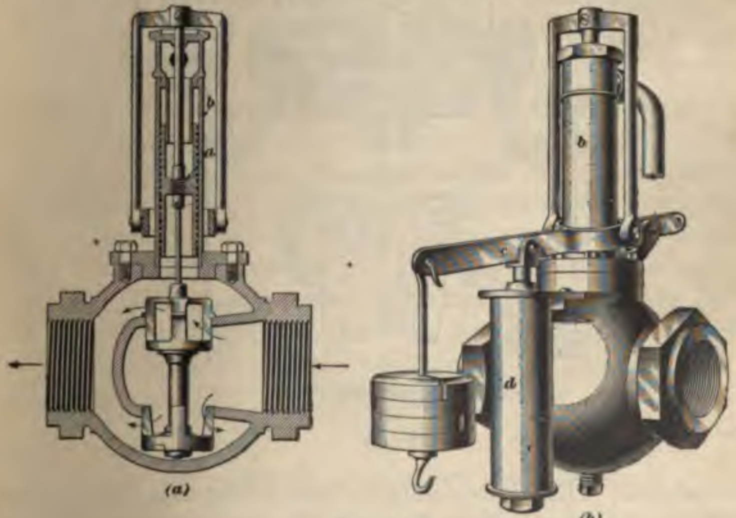


FIG. 4

12. For a moderate difference in pressures, reducing valves are made with the same size inlet and outlet, as

shown in Fig. 4. The construction is such that the upper side of the diaphragm receives the pressure of the low-pressure side *a*; the weight acts on the lower side of the diaphragm. This construction obviates the need of a balance pipe. The operation of this valve is essentially the same as that of the valve previously described, except that the valve proper moves *up* to open and *down* to close the steam outlets.

13. For work where the ratio of the pressures on the receiving and delivery side of the valve is very small—as occurs, for instance, in a plant where compound and simple engines draw steam from the same battery of boilers, and where the steam pressure used for the compound engine is too high for the simple engine—the Kieley reducing valve is made without a diaphragm; a small piston is substituted for the latter and a dashpot similar to that shown in Fig. 1 is fitted to prevent too rapid a motion of the valve.



(a) (b)

FIG. 5

14. The **Davis pressure-regulating valve,** shown in section in Fig. 5 (*a*) and in full in (*b*), is a double-seated

valve in which the diaphragm is omitted and a piston *a* working in a cylinder *b* is used instead. The piston is made tight by being steam packed, which means that a number of sharp-edged concentric grooves are turned in it, which fill with water and prevent the steam from passing. A weight on the lever *c* tends to close the valve; the steam pressure on the under side of the piston *a* tends to open it. The operation of the Davis valve does not differ from that of the Kieley valve shown in Fig. 3. To prevent rapid movement and, consequently, slamming of the valve, a dashpot *d* is fitted.

15. Spring-Loaded Reducing Valves.—The **Foster "Class W" reducing valve** belongs to the type in which the weight is replaced by a spring. The valve proper is double-seated, as shown in Fig. 6, and hence is very nearly

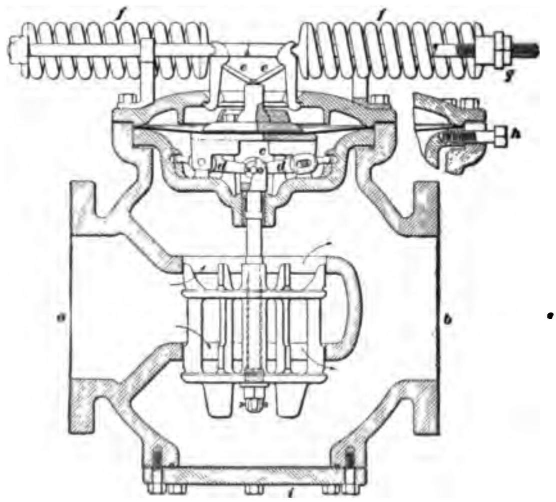


FIG. 6

balanced. The high-pressure steam enters at *a*; the steam on the low-pressure side *b* enters the diaphragm chamber *c* through a small port. In order to give a large movement of the valve with a small movement of the diaphragm, the valve is attached to levers *d*, *d* operated by the diaphragm.

The pressure on the under side of the diaphragm tends to force it upwards, thus closing the valve; this is resisted by the springs *f, f* acting through the togglejoint *e, e*. The tension of the springs is changed by the nut *g*; by this means the valve is set for different pressures. In order to extend the ratio between the receiving and delivery pressures, the port leading to the diaphragm is made adjustable in area by a screw valve *h*, by which means the steam entering the chamber can be reduced in pressure.

Since this valve is without a weight, it can be used on steam vessels, as it is not affected by the rolling and pitching of the vessel. The valve has a low-pressure outlet at *b* for a horizontal run; the low-pressure piping can be attached at the bottom, however, in which case the blank flange *i* is bolted over the opening *b*.

AIR VALVES

PURPOSE

16. **Air valves** and **cocks** provide for the escape of air from radiators, tanks, etc., where steam is used for heating. The valves are usually automatic, having an expansion device to close the valve when its temperature has reached the temperature of the steam. Some of these are fitted with a float device; when water accumulates in the valve by condensation, or is drawn in by capillary attraction and by the velocity of the air discharge, the device will close the valve until the pressures are equalized in the valve, and the water falls back into the radiator by gravity.

AUTOMATIC AIR-ESCAPE VALVES

17. The **Onderdonk air valve**, shown in Fig. 7, consists of a metal body having a metallic spring *c* placed in the case; a chamber is connected to the body. This chamber has at its upper end a small opening fitted with a threaded

sleeve having a port through it and a seat for the valve *b*. The valve consists of a metal rod extending through the spring, with a shoulder to admit of the expansion of the spring lifting the rod to close the port; a float *a* is fastened to the rod, so that water accumulating in the casing or chamber will lift the rod and close the port independently of the spring. While the valve is open, the air escapes through a hole in the cap *c*. When the steam reaches the spring *e*, the heat causes it to bend upwards, thus closing the valve. The spring is made of two different metals firmly soldered together; each metal expands a different amount when heated, thus causing the spring to bend.

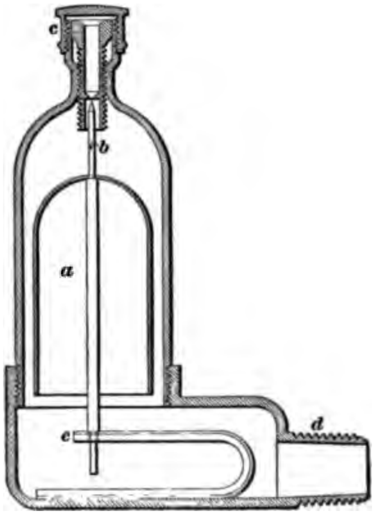


FIG. 7

18. The **Davis valve** is similar to the Onderdonk, except that the stem *a*, Fig. 8, that carries the float is made of vulcanized rubber. The stem expands when the steam reaches it, and the valve thus closes. The bottom of the stem is confined sidewise by the pin *b*; the stem, while the valve is free from water, rests on the perforated spider *c*. In this valve, as in all others, the sleeve *d* is threaded to provide for proper adjustment, so that the port will be closed upon expansion of the stem *a*.

FIG. 8

19. The Van Auken valve, shown in Fig. 9, differs from the Davis valve chiefly in that the float *a* is not fastened to the expansion stem *b*, but simply rests on top of it. In order that the valve may not become choked with water, an equalizing tube *c* leads to nearly the top of the casing; steam from the radiator flows through this pipe and insures that there is a steam pressure in the top of the casing equal to that in the radiator. In consequence of the equality of pressures, any water carried into the valve can drain back into the radiator by gravity through the channel *d*.

FIG. 9

20. The Russell valve, shown in Fig. 10, differs radically from those previously described. It contains a closed, hollow, copper float *a* having corrugated ends, the needle valve *b* being soldered to the top head. The float is partially filled with alcohol and normally rests on the bar *c*. When the air has passed out and steam reaches the float, its heat vaporizes some of the alcohol and causes a pressure in the float, which forces the heads outwards, thus elongating the float and seating the needle valve. In case a slug of water enters the valve, it buoys up the float and thus closes the valve. The water collecting in the pocket *d* drains

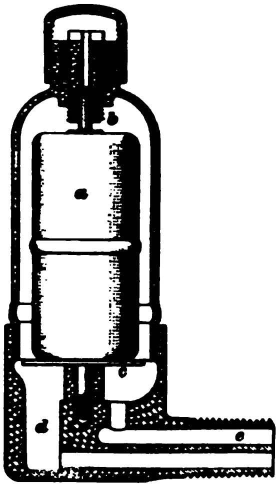


FIG. 10

back into the radiator, since steam entering through the upper passage *c* establishes a pressure above the water equal to that in the radiator.

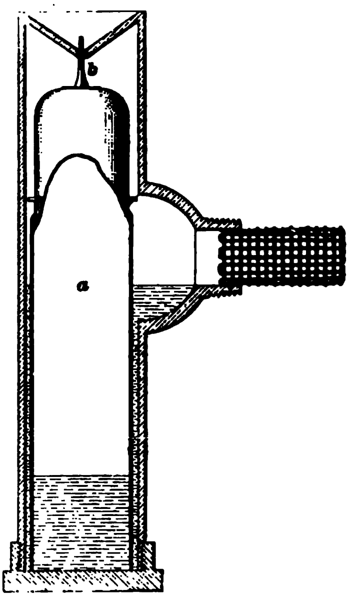


FIG. 11

21. The Libra automatic air valve, shown in Fig. 11, is operated by the expansion of air when heated. It contains a float *a* open at the bottom and carrying the needle valve *b* at the top; the lower end of the float is sealed by water. When the valve is cold, the float is down and the little port at the top open for the discharge of air; when steam reaches the float, it expands the air contained therein, and causes the float to rise, thus closing the air outlet. When the heat subsides, the air in the float contracts and, consequently, the float drops, thus opening the air outlet again.

AUTOMATIC AIR VALVES WITH DRIP CONNECTION

22. Purpose.—The air valves described in the preceding articles are designed to prevent the escape of water from the radiator through the air outlet, for the purpose of overcoming the danger of spoiling the floor, ceiling, and furniture by the escaping water. A somewhat different class of automatic air valves is designed to permit the escape of both air and water, closing automatically when reached by dry steam. A drip pipe is attached to the air outlet to carry away the water discharged and the disagreeable odors so common to air vents.

23. Construction.—The **Breckenridge valve,** shown in Fig. 12, belongs to the class mentioned in the preceding article. The valve *a* is fastened to a brass spring *b* bent as shown; when the whole valve is cold the valve *a* is away from its seat, and air and water can discharge freely into the drip pipe *c*. When steam reaches the spring, the heat causes the spring to curve more, which draws the valve *a* to its seat and thus closes the outlet.

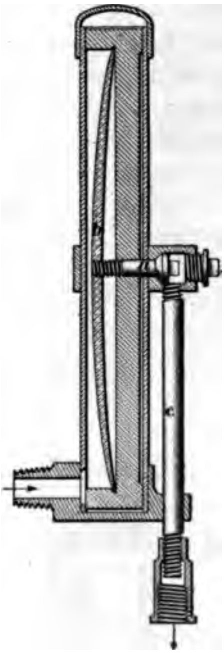


FIG. 12

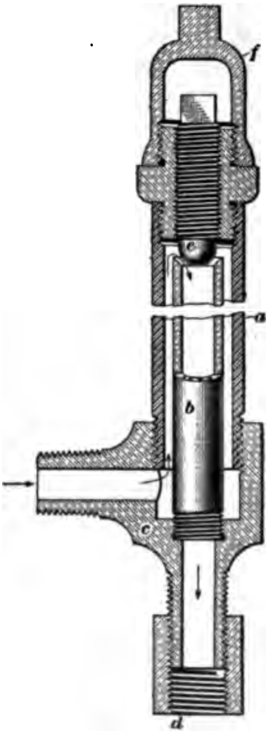


FIG. 13

24. The **Baker valve,** shown in Fig. 13, depends for its action on the difference in expansion of brass and iron, the brass expanding more than the iron. The casing *a* is wrought iron; the brass expansion pipe *b* is screwed into the valve body *c* in line with the drip outlet *d*. The upper

end of *b* is beveled, as shown; upon expanding it bears against the ball-shaped end of the screw *c*, thus closing the outlet. The adjustable screw *c* is protected by the bonnet *f*, which prevents unauthorized persons from meddling with the adjustment, and at the same time makes a neat finish.

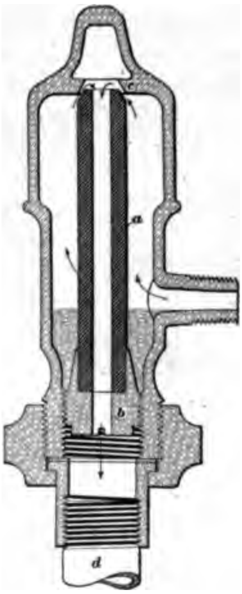


FIG. 14

25. The **Marsh "Paul" valve,** shown in Fig. 14, has a vulcanized-rubber expansion pipe *a* having a cone-shaped end; this expansion pipe is carried by the adjusting plug *b*. The conical seat *c* is formed in the casing, and the air and water discharge through the hole through *a* downwards into the drip pipe *d*, as shown by the arrows. Owing to the position of the adjusting plug, it is well protected against meddling when the valve is connected up.

26. The **Jenkins valve** has a solid vulcanized-rubber expansion plug *a* placed horizontally, as shown in Fig. 15. This plug is set rigidly into the adjusting plug *b*; its end, when expanded, bears against the raised flat seat at *c*. The drip pipe *d* is connected to the union shown.

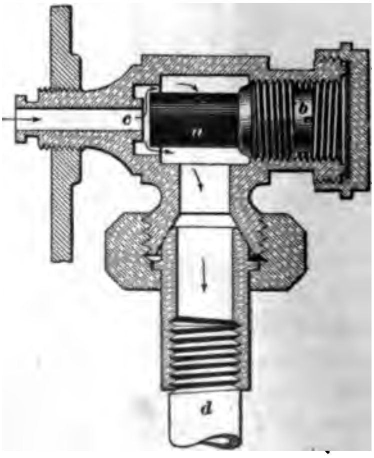


FIG. 15

27. Drip Cup.—Instead of connecting the drip outlet to a drip pipe to carry away any water discharged from the air valve, a drip cup is sometimes attached

to the valve. This is simply a cup-shaped vessel open at the top and having a central threaded stem for attaching it to the drip outlet. The cup is intended to empty itself by the slow evaporation of the water discharged into it; consequently, if the water enters the cup faster than it evaporates, the cup will overflow. Furthermore, with a drip cup, as well as with air valves without drip connection, the air is discharged directly into the room. In case the water in the boiler is foul, this air will have a noxious odor, which is another objection to the use of the drip cup.

AIR COCKS

28. An **air cock** is used for the same purpose as an automatic air valve, but as it is not automatic in its action, it is in that respect inferior. It must be used where high-pressure steam is employed for heating, where the variation in temperatures is such as to rapidly destroy the expansion devices of automatic air valves. It is also largely used on work where cheapness is more essential than quality.

29. The three most common forms of air cocks are shown in Fig. 16, where (*a*) illustrates the **tee-handle cock,** most commonly known as a **petcock.** This is a brass plug cock having a metallic handle, and is open to the same objection existing against all plug cocks used for

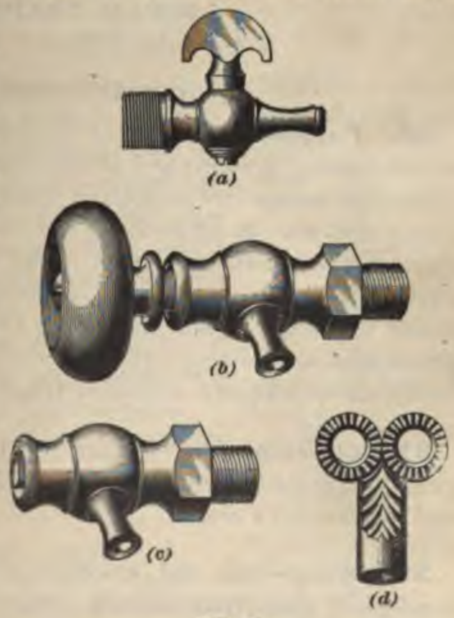


FIG. 16

steam work; namely, that the plug will, after some use, stick so tightly to the shell as to make it very difficult to open or close it. The better classes of air cocks are made in the form of an angle valve, as shown in Fig. 16 (*b*), and are known as **compression air valves.** A wooden hand wheel allows the valve to be operated while hot without the danger of burning the fingers. The air cock shown in Fig. 16 (*c*) is known as a **lock-shield cock**; it is of the compression type and is operated by a removable key, shown in Fig. 16 (*d*), which has a square socket fitting the square end of the valve stem. It is used where it is deemed advisable to prevent unauthorized persons from meddling with the radiator, as in schools, churches, and other public buildings.

STEAM TRAPS

INTRODUCTION

30. Purpose.—The water of condensation occurring in steam-heating systems and steam piping in general must be allowed to escape freely, both in order to admit uncondensed steam and also to prevent an accumulation of water that may produce *water hammer.* The use of an open drain pipe for this purpose is very objectionable, as it will allow steam to escape as well as water; to prevent the escape of steam and at the same time to allow the water to escape freely, devices known as **steam traps** are employed.

31. Classification.—Steam traps are divided into three general classes known as *water-seal traps*, *discharge traps*, and *steam-return traps.*

32. Water-seal and discharge traps only allow the condensed steam to drain into a place where the pressure is lower than that to which the trap is subjected, as, for instance, into the atmosphere. They cannot raise the water to a height greater than that corresponding to the pressure

in the system they drain, which height, in feet, is theoretically 2.3 times the steam pressure, and may be taken in practice as 1.4 times the steam pressure, in pounds per square inch. Thus, with a pressure of 2 pounds in the system, the water cannot be forced to a greater height than $2 \times 2.3 = 4.6$ feet. This is the maximum height, but the working height should not exceed $2 \times 1.4 = 2.8$ feet.

33. Return traps are designed to discharge the water into vessels having a pressure greater than that in the system drained by them, as, for instance, when the water is to be returned to a high-pressure boiler. They can also be used to elevate the discharged drain water to heights beyond the capabilities of the discharge trap.

THE WATER-SEAL TRAP

34. A water-seal trap, often called a **siphon trap**, is shown in Fig. 17. It is made entirely of pipe fittings and pipe. The drained water enters through *a* and leaves through *b*. The water contained in the trap is forced up the leg *d* and down the leg *c*, overflowing into *b* whenever the pressure in *a* rises enough. An air-vent pipe *e* prevents any possible siphonage. The use of this trap is limited to very low-pressure steam-heating systems, and its operation is so unsatisfactory that its use cannot be recommended.

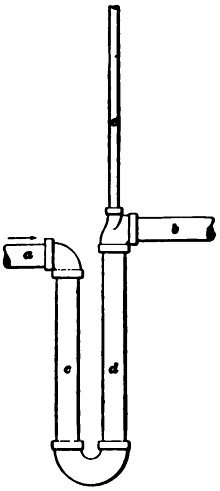


FIG. 17

THE DISCHARGE TRAP

35. Types.—There are three types of discharge traps in common use, known, in accordance with their operating device, as *bucket traps*, *float traps*, and *expansion traps*.

36. Bucket Traps.—The trap shown in Fig. 18 belongs to the bucket-trap type. Fig. 18 (*a*) is a vertical section through the center of the outlet, and (*b*) a perspective outside view. It consists of a receptacle *a* to catch the accumulated water and is fitted with a removable end plate to which the inlet and outlet connections are made, and to which the operating mechanism is secured. The float, or bucket, *b* is open and hinged to the end plate of the trap; the valve spindle *c* is hinged to the float and works in a sleeve *d*, which acts as a siphon and has a seat at the upper end for the pointed valve; this sleeve is screwed into the discharge port *e* of the trap. A by-pass valve *f* is arranged in the body to allow steam to be blown through into the discharge pipe to clear it of obstructions. The trap is caused to act by the accumulating water entering through the inlet port *g*, Fig. 18 (*b*), and flowing over the sides of the float, thus causing it to sink and drawing the spindle and valve from the seat, allowing the steam pressure to drive the water out of the bucket through the outlet port until the buoyant effect of the water outside the bucket again closes the valve. For low pressures a balanced valve is used.

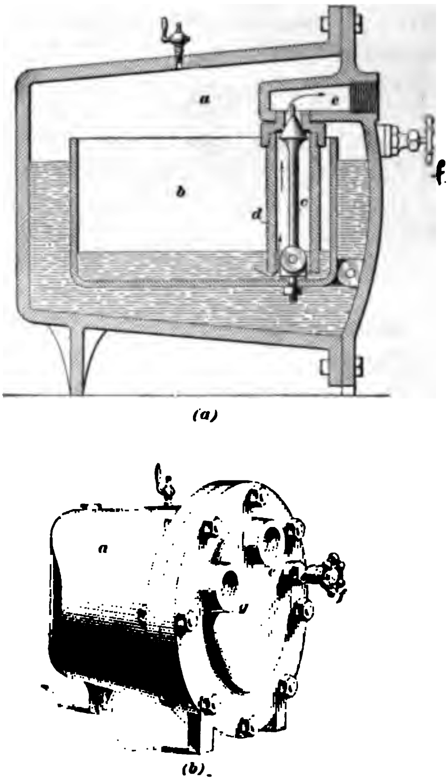


FIG. 18

37. Fig. 19 shows the **Nason trap.** The bucket *a* floats in the water, holding the end of the spindle *b*, which is made with four wings, against the seat in the cover. The

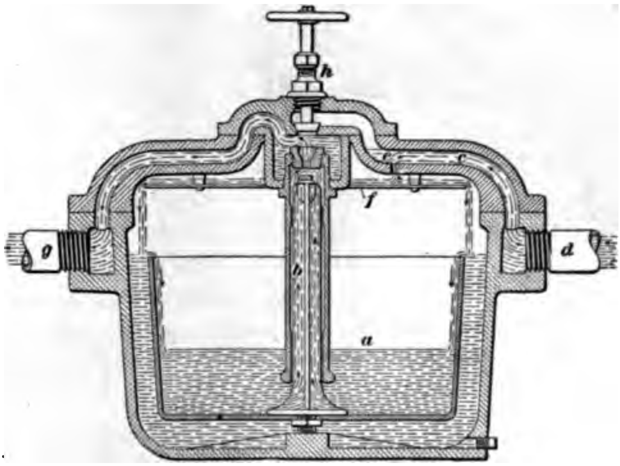


FIG. 19

water entering the inlet chamber *c* from the inlet *d* passes through an opening *e* into the body of the trap. A diaphragm *f* to diffuse the water towards the sides is placed beneath the opening, so that the water will fill the body and overflow into the bucket, which opens the valve by falling. The water in the bucket is forced by the steam pressure through the sleeve, around the spindle, and through the discharge chamber into the discharge pipe connected at *g*. A by-pass *h* is provided at the top to allow steam to be blown through the discharge pipe.

38. Fig 20 shows another form of bucket trap, or more strictly speaking, a **tank trap,** called the **Bundy** or **Littlefield.** This trap consists of a tank or pear-shaped chamber *a* for receiving the water of condensation, which passes into the tank through an opening *b* in the trunnion at one side, and passes out through the bent pipe *c* inside the tank.

The tank is pivoted on the two trunnions and is counterweighted by a lever and weight which overbalance the weight of the tank; the whole rests in a framework. The discharge port is inside the standard *c* and leads to a globe valve *d*, which has an elongated spindle attached to a projection on the end of the tank near the trunnions; the action of the trap is caused by the weight of the water that accumulates in the tank overbalancing the counterweight.

FIG. 20

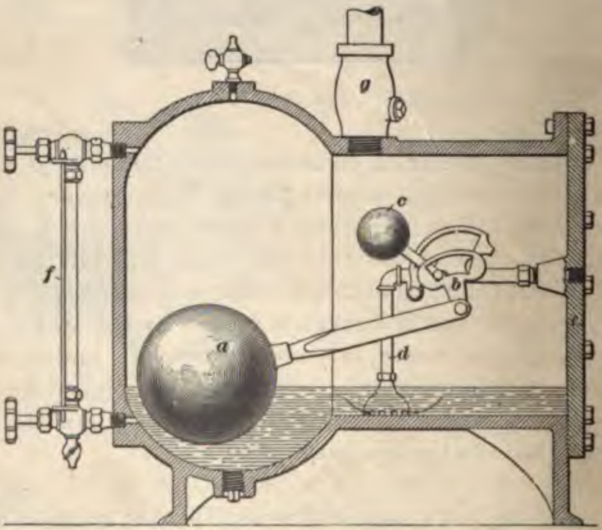


FIG. 21

The tank, in falling, lifts the valve stem and disk from the seat, and allows the pressure of steam to force the water from the tank through the discharge port and valve until

the tank is empty; the counterweight then brings the tank back into position and closes the discharge valve.

39. Float Traps.—Float traps have a closed hollow float that rises and falls with the height of water and operates a valve. The **Century trap,** shown in Fig. 21, has a float *a* attached to a bell-crank lever *b*, which on rising suddenly throws over a weight *c* and forces a valve in the discharge pipe *d* to open, the pressure thereby draining the water to the proper level through the discharge pipe connected to the head *e*. A gauge glass is located at *f*, so that the water-line in the trap can be observed. A strainer is located at *g* to keep out dirt.

40. In the **Davis trap,** shown in Fig. 22, the float operates a pair of valves *a*, secured to a beam *b*, one valve rising from the seat while the other is being depressed into the discharge chamber. As both valves are in balance, the trap will operate under any pressure.

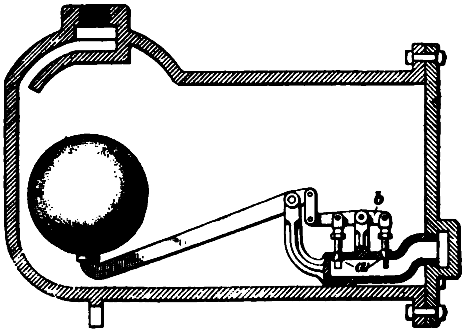


FIG. 22

41. There are many other float-operated traps in the market, but as their operation does not differ essentially from that of the traps here illustrated, no difficulty should be experienced in studying out their operation. Nearly all makes of traps are provided with a petcock, which permits the air to be discharged from the trap in starting up.

42. Expansion Traps.—Expansion traps are similar to automatic air valves fitted with an expansion device, in that they permit the escape of relatively cold water, but close upon the steam coming in contact with a suitable expansion device. As they will discharge air as readily as water, they

do not need a petcock. Expansion traps are now used quite extensively, and as made today are quite reliable.

43. The expansion trap shown in Fig. 23 has a brass tube *a* screwed into a pair of cast-iron saddles, or yokes, *b*, *b'*; one end of each yoke is rigidly secured by an iron bolt *c*. A rod *d* with an adjusting thread and locknut is attached to the yoke *b*, while to the yoke *b'* a short link *e* is hinged, which is pivoted to the rod *d*. A discharge valve *f* is placed near the saddle at this end; it has a sliding spindle and a light spring that holds the valve wide open. Steam admitted at the inlet end *g* causes the brass tube to expand, forcing the yokes apart. As the rod *c* does not expand, the brass pipe, as well as the rod *c*, bends slightly during its expansion; the right-hand end of the saddle *b* then moves upwards by an amount nearly double the increase in length of the brass pipe, pulling the rod *d* with it. As this is hinged to the link *e*, its lower end is constrained to move towards the valve, thus closing it. A slight reduction in temperature, due to water entering the trap, causes the valve to open wide again, as the combination of the yoke *b*, rod *d*, and link *e* gives a large sidewise movement of the lower end of *d* with a small change in the length of *a*.

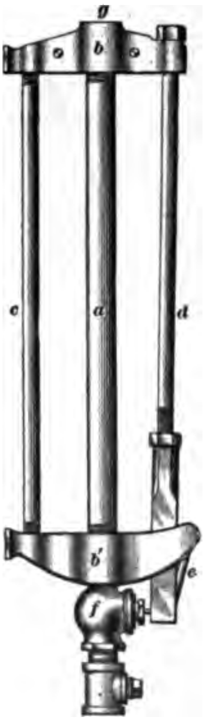


FIG. 23

44. Fig. 24 shows the **Geipel trap.** This trap has a brass pipe *a* and iron pipe *b* screwed into the base *c* and valve body *d*. The iron pipe is inclined in respect to the brass pipe. The expansion of the brass pipe, which is greater than that of the iron pipe, forces the valve body *d* upwards

by springing the iron pipe. The valve *e* is a simple sliding-stem valve, which, through the upward motion of the valve body, is forced to its seat by coming in contact with the adjustable stop *f*. To prevent injury to the valve and its seat, the stop is arranged to yield after the valve is seated, the stop being held in place by the spring *g*. The stop is adjusted by means of the locknuts shown at *h*. The water

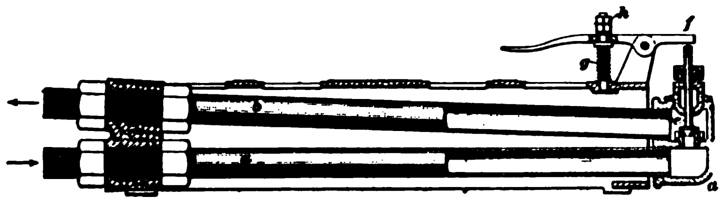


FIG. 24

of condensation enters the brass pipe and cools it sufficiently for the valve body to descend; the valve *c* is now opened by the steam pressure behind the water, as its stem is away from the stop *f*, and the water passes out through the iron pipe. As soon as the steam reaches the brass pipe, the upward motion of the valve body closes the valve *c*, as previously explained.

45. The Jenkins "Diamond" trap is identical in construction and operation with the Jenkins automatic air valve, illustrated in Fig. 15, the only difference being that it is larger.

46. Expansion traps are capable of handling successfully a large amount of condensation. They are not as liable to freeze as float traps and bucket traps, and are therefore better for exposed locations. They are well adapted for high-pressure work, as, for example, for engine drip pipes, as they automatically free the engine cylinders and steam jackets of water. Expansion traps are also well adapted for use in places where the condensed steam contains much grease and oil. The valve always opens wide and the rush of water automatically cleans the valve

and seat. Hence for such water they are superior to bucket and float traps, as in most designs of these traps the valve opens but slightly for the escape of the water, in consequence of which the grease and oil will choke the opening and thus interfere with the free discharge of the water.

RETURN TRAPS

47. The principal use of return traps is for returning water of condensation to the boilers. The distinguishing feature of all return traps is that they are provided with a live-steam connection and an automatic valve operated by the float or other device controlling the emptying of the trap, which valve admits live steam to the trap to make the pressure within it equal to that in the boiler into which it drains.

48. An example of a return trap is given in Fig. 25, which represents the **Curtis return trap.** It consists of a receiver *a* containing the float *i* and having connected to it the water inlet pipe fitted with the check-valve *d*, the live-steam inlet pipe fitted with the stop-valve *b*, and the water outlet pipe fitted with the check-valve *c*. A rotary valve *e* serves to admit live steam to the trap. It is connected, by the rod *g*, to the rocker *f* by a stud working in a curved slot. The rocker *f* is engaged by a pin in the lever *h*, which carries the float *i* on one end and a counterweight on the other.

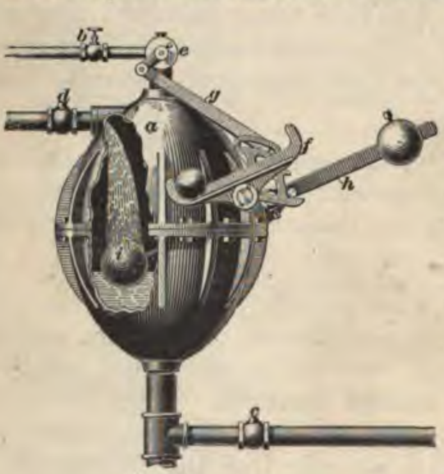


FIG. 25

49. The operation is as follows: At first the live steam is shut off. As the water of condensation flows into the receiver, the float *i* rises and the loaded end of *h* descends. The stud in *h* engages a lug of the rocker *f*; the latter rotates right-handed until the track confining the ball, shown on *f*, is inclined to the right. The ball now rolls down the track and causes the rocker *f* to rotate to its limit, which pulls open the valve *c* and admits live steam to the trap. The receiver now empties, and as the float *i* descends, the rocker *f* will finally be rotated left-handed, which closes the steam valve. The operation is now ready to be repeated. The check-valve *d* prevents the live steam blowing back into the system that is drained by the trap; the check-valve *c* prevents the water in the boiler from backing up into the trap.

50. The **Bundy return-steam trap** is shown in Fig. 26. It consists of a body *a* that receives the water and that is pivoted at *b* and *c* to the stationary part of the trap. The water enters the trap at *b* and fills the part *a* until the weight of the contained water is sufficient to overbalance the weight *d*, when *a* sinks downwards until it comes against the guide *g*. This downward motion causes the lug *e* to engage

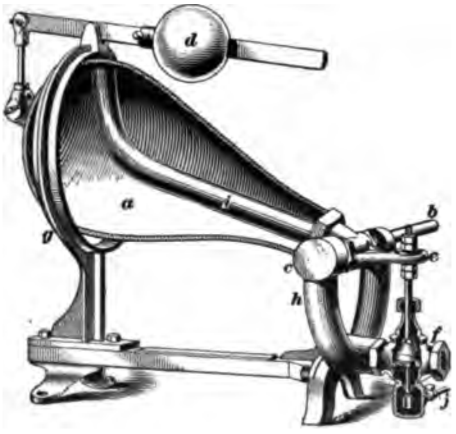


FIG. 26

the upper nuts of the steam valve *f*, opening the latter and at the same time closing a small air valve placed below *f*, thus admitting steam at full boiler pressure on top of the water; the steam flows through the hollow leg *h* of the yoke

and the pipe *i*. The water now flows to the boiler by gravity, leaving the trap through the same pipe it entered, being able to enter the boiler by reason of its hydrostatic head. As soon as the trap is sufficiently empty, the weight *d* pulls the trap body to its upper position, which closes the steam valve and allows air to enter the trap body through the pipe *j*. The operation is now repeated.

51. The piping up of a Bundy trap is shown in Fig. 27. In case of a heating or steam-pipe drainage system, the

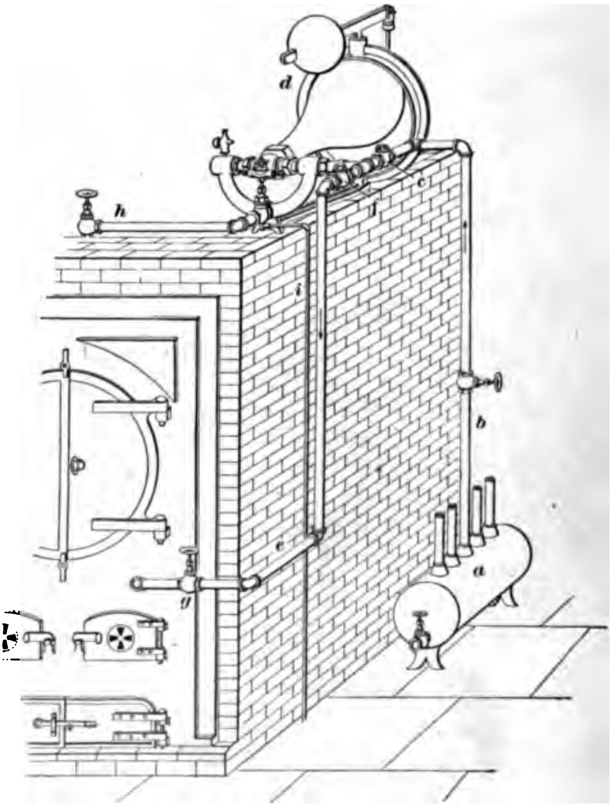


FIG. 27

different drains lead to a receiver *a*, whence the water passes to the trap *d* through the pipe *b* and check-valve *c*. The

feedwater leaves the trap and passes to the boiler through the feedpipe *e*, the check-valve *f*, and the globe valve *g*. The check-valve *c* prevents the water or live steam in the trap blowing back into the receiver, while the check-valve *f* prevents the water in the boiler backing up into the trap. Steam is admitted to the trap through the pipe *h*; a vent pipe *i* is usually attached to the air valve at the base of the steam valve and conveys to the ash-pit the steam left in the trap after it is emptied of water.

52. When there is not sufficient pressure available to make the water in the receiver enter the trap on top of the boiler, another trap may be placed at the point where water will flow into it. This trap may then be made to discharge into one placed on top of the boiler, using steam from the boiler as a motive force.

53. Return traps can also be used for discharging the water into elevated tanks, the height to which the water can be raised depending on the available boiler pressure. This height in feet, allowing for frictional and other resistances, is given by multiplying the boiler pressure available by 1.4. Thus, if the boiler pressure is 60 pounds per square inch, a return trap can discharge into a tank 60×1.4 or 84 feet above it.

SPECIAL STEAM-FITTING ACCESSORIES

TANKS

PURPOSE

54. Tanks are used for various purposes in steam-heating and steam-fitting work; they are employed chiefly as *blow-off tanks*, *drip tanks*, and *hot-water tanks*.

55. A **blow-off tank** is a receptacle connected to the blow-off pipe of a boiler or battery of boilers; its purpose is to provide a place in which the hot water blown out of the

boiler may cool down before it is discharged into a sewer. Its use is obligatory in all places where the sanitary code prohibits the discharge of hot water into a sewer.

56. Drip tanks serve practically the same purpose as blow-off tanks; they receive the water of condensation drained from steam-heating systems, engines, separators, their piping, and similar apparatus, and cool it to a sufficiently low temperature to permit it to be safely discharged into a sewer. They are used for this purpose in places where it is deemed inadvisable to return the hot drain water to the boiler. In some cases drip tanks simply serve as reservoirs from which the hot water is drawn for return to the boiler, or for other purposes, as required.

57. Hot-water tanks are receptacles for the storage of a large volume of hot water; they generally are provided with a coil of pipe through which steam flows in order to heat the contained water. They are used in hotels, apartment and flat houses, and large private residences, for the purpose of supplying hot water to the plumbing fixtures.

CONSTRUCTION

58. Blow-off, drip, and hot-water tanks are generally constructed of steel plate; they have a cylindrical shell with

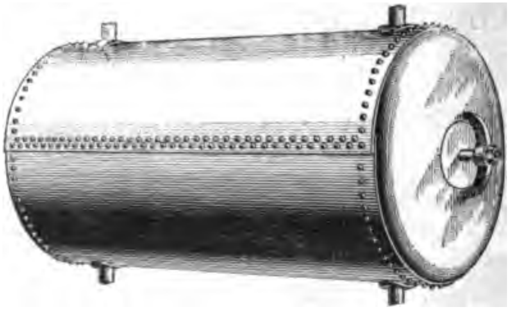


Fig. 28

a double-riveted longitudinal seam and are closed by dished heads single-riveted to the shell, as shown in Fig. 28. A

manhole is generally placed in each head. In order that the contained water may be cooled quickly, or be heated, a coil made up of pipe and fittings is placed inside; cold water circulates through this coil when the tank is used as a blow-off or drip tank.

59. A good construction of a cooling coil, and the method of connecting it to the shell of the tank, is shown in Fig. 29.

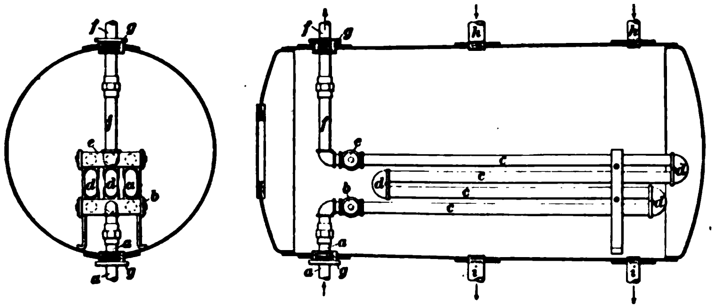


FIG. 29

The coil is made from pipes and fittings; the cooling water enters through the pipe *a* and passes into a manifold *b*, whence it passes through the pipes *c*, *c* and return bends *d*, *d* into the manifold *e* and leaves through the pipe *f*. The number of coils to be used depends on the amount of cooling surface desired. The pipes *a* and *f* screw into large bushings *g*, *g* threaded outside to fit a tapped hole in the shell, and tapped inside to suit the pipe. By substituting different bushings, the size of the inlet and outlet connections is readily changed. The blow-off or drip connections can be made to the tank at *h*, *h*, and the drain pipe to the sewer may connect to *i*.

60. Fig. 30 illustrates the **Kensington heater**, which may be used as a drip tank, blow-off tank, or hot-water tank, depending on the pipe connection. The coil *a* through which the cooling or heating medium passes is attached to a plate *b*; by taking off the head *c*, the coil can be removed from the heater. If used for heating water, the steam enters at *d* and leaves at *e*; if water is used to cool water discharged

into the tank, it enters at *c* and leaves at *d*. When used to heat water in the tank, the latter enters cold through the pipe *f* at the bottom and leaves hot through the pipe *g* at the top; when used as a blow-off tank or drip tank, the

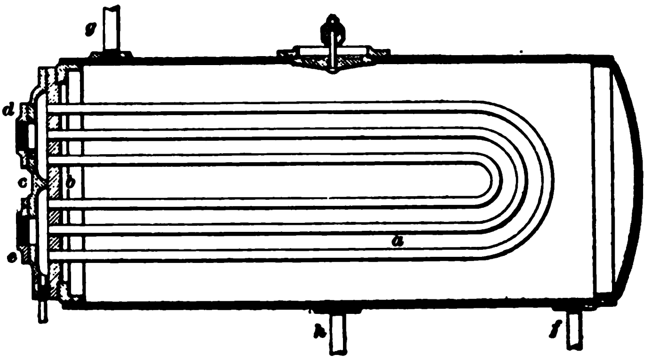


FIG. 30

drain water enters at *g* and leaves at *f*. A waste pipe *h*, closed by a valve, is used for periodically blowing out part of the water in order to remove sediment, in case the tank is used as a hot-water tank.

61. In places where but a relatively small amount of drain water from heating systems is to be cooled before being discharged into a sewer, cast-iron **catch basins**, made as shown in Fig. 31, are often used; they are buried in the ground. The catch basin is fitted with a siphon connection *a*, which insures an automatic emptying at intervals, depending on the amount of water discharged into it. A manhole is placed in the top to give admittance for cleaning. The standard size in the market is 36 inches

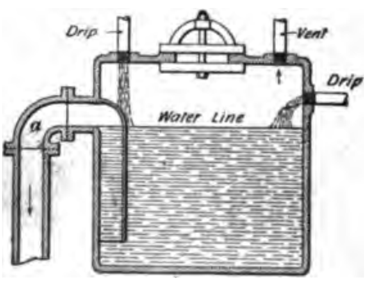


FIG. 31

diameter by 36 inches high, having a manhole 10½ inches by 14½ inches.

62. The bottom of the catch basin must be placed above the level of the sewer, in order that the water may be siphoned from it; if this cannot be done, the water must be pumped from it. In order that the water may enter the catch basin freely, a vent pipe leading above the ground and open to the atmosphere must be screwed into the top.

SIZES OF TANKS

63. The kind of tank shown in Fig. 28 is made in standard sizes by the different manufacturers. While there is no perfect uniformity in regard to standard sizes, a good idea of the general size of tanks may be obtained from Table I, which gives the practice of the Titusville Iron Company.

64. A blow-off tank should have a volume at least equal to one-third the volume of water contained in the boiler draining into it, and be as much larger as circumstances will permit, especially when the tank has no cooling coil.

65. Drip tanks receiving the water of condensation from a steam engine exhausting into the atmosphere, and from its piping, are generally given a volume equal to one-tenth the volume occupied by the water consumed, in the form of steam, by the engine in 1 hour. It is recommended, however, never to use a tank smaller than 3 feet diameter and 6 feet long. The water consumption of the average engine is about 30 pounds per horsepower per hour, and one-tenth of this is 3 pounds. Hence, by multiplying the horsepower of the engine by 3 and dividing the product by 8.3 (the number of pounds of water in a gallon), the volume of the drip tank, in gallons, is obtained.

66. Drip tanks receiving the total water of condensation from a building and the engine exhaust condensation from feedwater heaters, etc., are simply storage chambers that receive temporary floods of water and store them until the pump or return trap that empties the drip tank can remove

them. The size of drip tank for such a case depends considerably on the volume of floods expected to exist at times. It is customary to allow 20 gallons of tank capacity for every 1,000 square feet of direct radiation. It is considered good practice not to use a tank smaller than 3 feet diameter by 6 feet long.

TABLE I

STANDARD SIZES OF WATER TANKS

Order Number	Diameter. Inches	Length. Inches	Thickness of Shell. Inch	Thickness of Heads. Inch	Capacity. Gallons	Weight. Pounds
1	24	60	$\frac{1}{4}$	$\frac{5}{16}$	117	490
2	24	72	$\frac{1}{4}$	$\frac{5}{16}$	141	560
3	24	84	$\frac{1}{4}$	$\frac{5}{16}$	165	660
4	30	48	$\frac{1}{4}$	$\frac{3}{8}$	147	570
5	30	60	$\frac{1}{4}$	$\frac{3}{8}$	184	660
6	30	72	$\frac{1}{4}$	$\frac{3}{8}$	220	740
7	30	84	$\frac{1}{4}$	$\frac{3}{8}$	257	840
8	30	96	$\frac{1}{4}$	$\frac{3}{8}$	294	940
9	36	60	$\frac{1}{4}$	$\frac{3}{8}$	264	840
10	36	72	$\frac{1}{4}$	$\frac{3}{8}$	317	940
11	36	84	$\frac{1}{4}$	$\frac{3}{8}$	370	1,040
12	36	96	$\frac{1}{4}$	$\frac{3}{8}$	423	1,140
13	42	60	$\frac{1}{4}$	$\frac{3}{8}$	360	1,010
14	42	72	$\frac{1}{4}$	$\frac{3}{8}$	432	1,120
15	42	84	$\frac{1}{4}$	$\frac{3}{8}$	502	1,250
16	42	96	$\frac{1}{4}$	$\frac{3}{8}$	575	1,390
17	42	108	$\frac{1}{4}$	$\frac{3}{8}$	648	1,540
18	42	120	$\frac{1}{4}$	$\frac{3}{8}$	720	1,670
19	48	72	$\frac{1}{4}$	$\frac{3}{8}$	562	1,350
20	48	84	$\frac{1}{4}$	$\frac{3}{8}$	658	1,490
21	48	96	$\frac{1}{4}$	$\frac{3}{8}$	751	1,600
22	48	108	$\frac{1}{4}$	$\frac{3}{8}$	846	1,800
23	48	120	$\frac{1}{4}$	$\frac{3}{8}$	940	2,000

67. The cooling coil of a drip tank that accumulates greasy water should have a cooling surface of not less than 1 square foot for every 6 gallons of tank capacity. This

allowance is much greater than is called for by calculations based on heat transmission through clean tubes, but the extra amount of cooling surface is necessary to allow for reduction in efficiency of the cooling surface by grease accumulation.

68. For a blow-off tank it is good practice to allow 1 square foot of cooling surface for every 10 to 15 gallons capacity. The amount of cooling surface allowed is less than for drip tanks because the water is comparatively free from grease.

TRENCHES

69. When pipes must be placed underground or beneath floors in buildings, they should not be laid in damp ground, and should be so placed that repairs can be made easily. To protect the pipes against dampness, they should be laid in brick- or concrete-lined trenches; proper hangers, which allow free expansion and contraction, should be built into the side of the trenches to carry the pipe. A good form of hanger, which can easily be made, is shown in Fig. 32. It consists of a cast-iron angle plate *a* having a half-round bearing to support a round iron bar *b* placed between a pair of angle plates, one on each side of the trench. A roller *c* is passed over the rod. The roller and rod can be removed at will for access to other pipes, and is easily replaced. The trench walls should be strong enough to resist the greatest pressure against their sides, and should be finished at the floor with a cast-iron curb; metal cover-plates with scored tops and in short sections should be placed over the trench; proper anchors to hold the curb should be fastened to the brickwork and flooring.

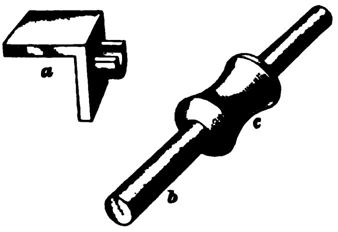


FIG. 32

70. A good trench construction is shown in Fig. 33. The bottom and side walls are built of brick or concrete,

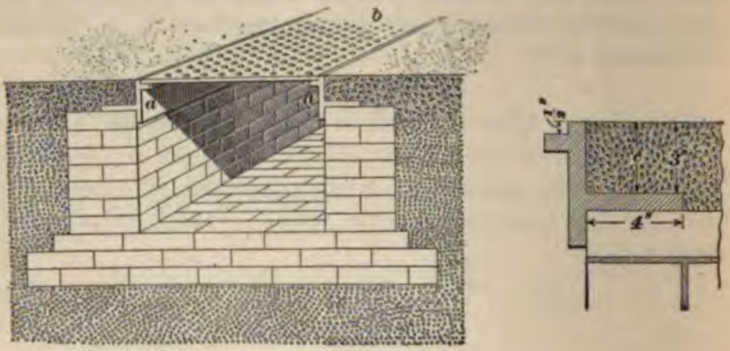


FIG. 33

and a cast-iron curb *a* is placed on top of the side walls, the curb having the cross-section shown. The 3-inch offset in the curb allows a concrete floor to be run close to the cover-plate *b*. If a wood floor is to be laid, the offset requires to be only 1 inch.

71. Cover-plates were formerly made of cast iron, but the use of cast iron for this purpose is being abandoned in favor of steel. Pressed-steel plates are cheaper and stronger

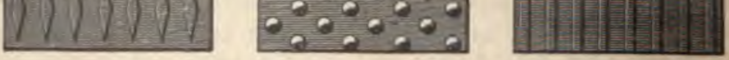


FIG. 34

than cast-iron plates; they can be obtained in various styles of scoring, the most common styles being shown in Fig. 34.

The object of scoring cover-plates is to have them present a better foothold than is given by smooth plates. If the cover-plates are very wide, they require stiffening, and supports, or braces, must be placed beneath them in order to prevent deflection under a load.

SPECIAL APPURTENANCES

72. In steam-heating and steam-fitting work, various cast or wrought fittings, differing from any heretofore shown, will often be required for special purposes. Most of these fittings are made to order only, and fully dimensioned sketches are required to be sent with the order. Some special fittings are shown in the following illustrations and their purpose explained.

73. Tanks placed close to the floor may be supported on two tank saddles made of cast iron. The form shown in Fig. 35 is known as the **Rutzler tank saddle,** and can be obtained for cylindrical tanks ranging from 24 inches to 48 inches in diameter.

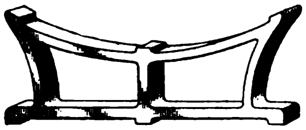


FIG. 35

74. A tank saddle may be made up of a piece of **T** iron bent to the shape shown in Fig. 36 and made to suit the curvature of the tank; the legs and braces are made up of pipe and are united by regular pipe fittings, screwed flanges serving for bases. A forked fitting must be made for each leg to unite it to the web of the bent **T** iron. An angle iron may be used instead of the **T** iron; it is more difficult to bend properly, however, is inferior mechanically, and does not present as neat an appearance.

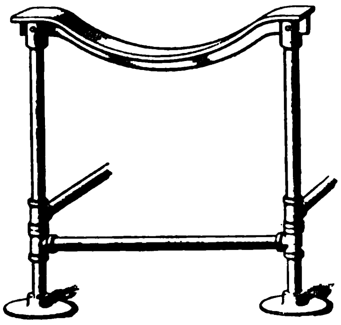


FIG. 36

75. In order to hang a cylindrical tank from **I** beams overhead, hangers may be made from flat iron, as shown in Fig. 37. Two bent clamps attached to each leg are used for clamping the hanger to the beams.

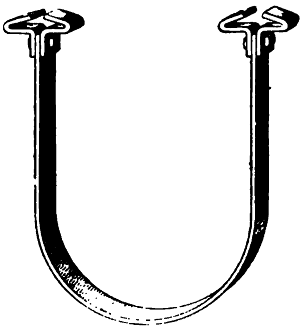


FIG. 37

76. For attaching brackets, hangers, etc. to a wall, **anchors** are used. These are made in various ways, the best kind passing clear through the wall. The simplest form is an iron rod threaded at both ends and passed through a hole cut through the wall; a large washer and nut is placed on one end and the bracket or hanger is attached to the other end. In order to dispense with the washer and nut, the anchor bolt is occasionally threaded on one end only; the other end is plain, and a short length is bent at right angles to the body to prevent the bolt from slipping through the hole. This construction is much inferior to the previous one. Sometimes an eye is formed on one end of the anchor bolt, and a piece of pipe is passed through the eye to prevent the bolt from slipping through the wall. This makes a bolt far superior to the one with a bent end, but still inferior to the threaded bolt with a large washer and nut.

77. For bridging over openings when much weight is to be placed above the opening, well-ribbed cast-iron plates or **I** beams may be used.

78. Vertical pipes may be supported either at the base, in which case a suitable support is placed beneath it, or by suspending them from the floor above. In the latter case a pipe clamp, made as shown in Fig. 38, may be clamped to the pipe. This clamp simply serves as a

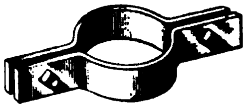


FIG. 38

collar to prevent the pipe from slipping through the floor. As it is made in halves, it is easily applied and removed.

79. A vertical pipe may be tied to a horizontal I beam by a strap made of band iron and bent to the shape shown in Fig. 39. After passing the strap around the pipe, the ends are hammered down over the flange of the beam, thus securing the strap permanently.

FIG. 39

EXPANSION DEVICES FOR STEAM PIPES

SWING JOINTS

80. Swing joints, often called **swivel joints,** are used to provide for the expansion and contraction of piping, and also for providing a swivel joint to allow the ready raising and lowering of connections to parts of machinery. Swivel joints can be made of ordinary fittings, but the constant screwing in and backing out of the threads causes them to leak, and hence they should be used only where the movement is very slight; they should have graphite smeared on the threads.

81. Regular swivel joints are made of brass, and can be obtained for the smaller sizes of pipe. A swivel joint consists of a fitting having a tapered plug, as *a* in Fig. 40, which is ground into a corresponding hole of another fitting. A central hole opening into a concentric recess of the plug is cored in *a*, in order to allow the steam to pass from one fitting to the other.

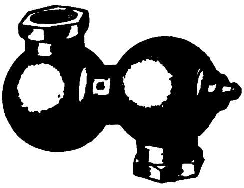


FIG. 40

EXPANSION JOINTS

82. Built-Up Expansion Joints. — Expansion joints are used to take up the expansion and admit the free contraction of long runs of steam pipe, which expands when steam is turned into it and contracts in cooling; they should be placed at intervals in long runs. The pipe should be secured with anchors, so that the expansion can take place towards each end.

83. The **Wainwright expansion joint,** shown in Fig. 41, consists essentially of a seamless drawn copper tube, which is corrugated, as shown at *a*; the ends of the tube are turned over the faces of cast-iron flanges, thus forming a gasket, as at *b*; bronze rings *c* are placed in the inside and outside corrugations, to reenforce them; the corrugations admit a certain amount of expansion and contraction of the joint. A metal sleeve *d* having a fitted end sliding in the copper sleeve and flange is fitted inside the joint to preserve alinement and reduce friction.

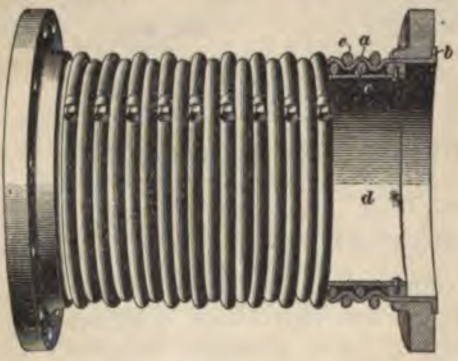


FIG. 41

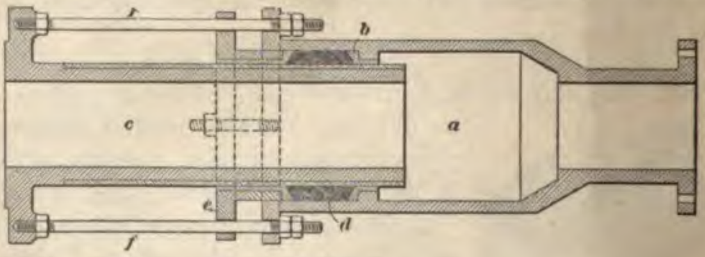


FIG. 42

84. Another form of joint is shown in Fig. 42. It is constructed with a cast body *a* having a shoulder into which

a brass bushing *b* is forced or screwed. A sliding sleeve *c* passes through the bushing, and packing is placed in the annular space *d* around it; a gland *e* is fitted around the sleeve. Stud bolts are fastened to the body and pass through the flange of the gland; screwing up the nuts on the bolts tightens the gland on the packing, thus making a tight joint around the sleeve. Stud bolts *f*, *f* are also fastened to the sleeve, passing through a flange on the body, to prevent the joint from blowing apart. Joints of the form shown are called **stuffed joints** and also **slip joints.** These joints need attention and repacking, and therefore are not held in as high favor by engineers as are those that need no attention, like the corrugated joint previously shown.

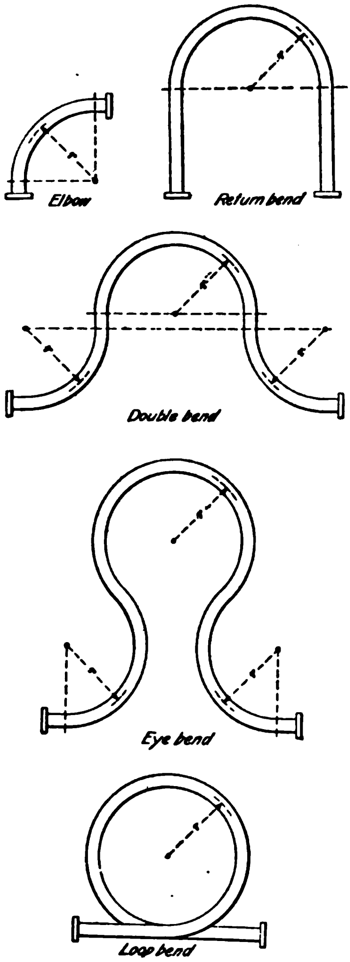


FIG. 43

85. Bent-Pipe Expansion Joints.—Properly, bent pipes make the best form of expansion joint, but the space they occupy often limits their use to places above ground or underground where sufficient room can be provided. The shortest radius, as *r* in Fig. 43, of bent pipes serving as expansion joints should not be less than 6 diameters of the pipe for wrought iron and steel, and to get the proper spring should be larger when used on long runs. These bends can

be advantageously used for engine connections and similar piping, as they tend to prevent vibration. The usual form of bends made are shown in Fig. 43, where the trade names are marked below each bend. Bends can have a shorter radius if copper pipe is used, as this yields easier. The large sizes of copper bends are hand-wrought and brazed; small sizes can be made from seamless drawn copper pipe. Brass pipe is also used, but cannot be bent to the required shape as easily as copper pipe.

86. Bends made from iron or steel pipe must be bent while heated red hot; seamless copper and brass pipes can be bent cold over a suitable form. Iron and steel pipe

(a) (b)

Fig. 44

bends generally have iron flanges screwed on; copper bends either have composition flanges riveted and brazed on, as shown in Fig. 44 (*a*), or they have wrought-steel flanges fastened by turning the edge of the pipe over, as shown in Fig. 44 (*b*).

PROTECTIVE COVERINGS

PURPOSE

87. Steam pipes and vessels containing steam or hot water are covered with materials that are poor conductors of heat, in order to prevent the loss of heat by radiation, and consequent condensation. Various materials are used for this purpose, some of which are fireproof, while others

are not. Fire-insurance companies generally require fire-proof covering to be used for steam pipes, especially when high-pressure steam, which has a correspondingly high temperature, is used.

SECTIONAL COVERINGS

88. Fig. 45 shows, before and after application, a length, or **section**, as it is usually called, of the **Nonpareil cork**

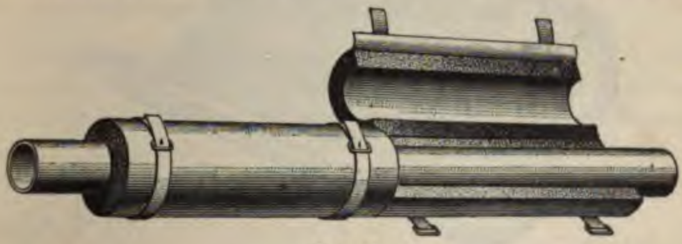


FIG. 45

covering, which is made of ground cork, subjected while under great pressure to a high temperature; this causes the natural gum in the cork to seal the pores, forming minute air cells. It is then fireproofed and finished with canvas and brass bands. As the lengths are made in halves, the covering can be readily applied to and removed from the pipes, it being secured by doubling the brass bands over.

89. The **Magnesia sectional covering** consists of about 85 per cent. of carbonate of magnesia mixed with long fiber asbestos to form a bond, and a small amount of calcite. It is halved, covered with canvas, and secured with brass bands.

FIG. 46

90. The **Asbestos air-cell sectional covering**, shown in section in Fig. 46, is made of asbestos paper of suitable thickness folded into flutes, and then placed in layers one on top of the other and secured together

with silicate of soda, forming air cells all through. The covering is made in halves, covered with canvas, and secured with metal bands.

91. Fig. 47 shows another form of air-cell sectional covering, similar in form to the one shown in Fig. 46, but

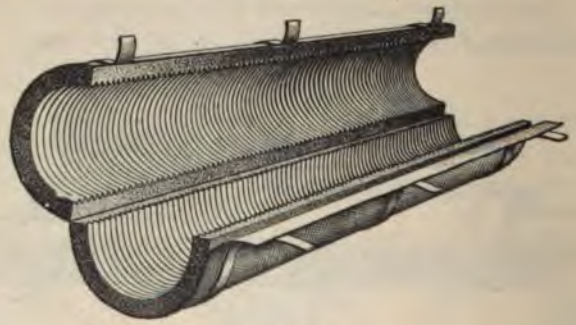


FIG. 47

having the air-cell formation in parallel rings around the pipe. It is called the **Asbestocel covering.**

92. Fig. 48 shows yet another form of air-cell covering,

FIG. 48

having short annular air spaces formed by concentric division rings. This covering is known as the **Hercules.**

93. The **Imperial covering** is an asbestos-paper covering formed by layers of indented paper so arranged as to permit air cells or spaces between each sheet; it is cut and

applied in the same manner as the coverings previously named.

94. **Fire-felt** is composed of long fibrous asbestos; it contains minute air spaces, like wool felt, except near the outside, where the pores are filled with finer asbestos to prevent circulation. The covering is slightly corrugated on the inside and is covered with canvas outside; it is applied in the same manner as other sectional coverings. Sizes above 4 inches inside diameter are made in halves.

95. The **Manville high-pressure covering** is a combination covering having an inner core of about half the thickness of the covering and composed of infusorial earth; around this, wool felt is wrapped, which is covered with canvas pasted on; the sections are in halves and fastened with metal bands.

96. Other combination coverings are used with more or less good results for preventing loss of heat in piping, but many of the cheaper grades of covering are found to contain sulphate of lime, and but little carbonate of magnesia, and such bonding material as cocoa fiber, sawdust, excelsior, hair, etc.; they are finished with canvas and secured with bands. The sulphates are corrosive, and should be used with care on iron or steel, and only where the pipe has been painted. All sectional coverings have fittings molded to suit the standard steam fittings, such as ells, tees, and valves.

UNDERGROUND COVERINGS

97. **Boxes.**—Steam pipes placed underground are often enclosed in wooden boxes, which should be lined with tin. Wooden boxing made without tin lining, if placed in close proximity to steam-heated surfaces, gradually becomes a soft pulp on the inside, and with high-steam pressures it soon chars and becomes the same as charcoal, although the color may not indicate that any change is effected until the air comes in contact with it. If it has not been in contact

with the atmosphere for some time, it may easily ignite, provided there is iron rust from the pipe mingled with the charred portion; when the atmosphere is admitted, the rust or oxide of iron absorbs the oxygen in the air so rapidly that it may ignite the charred wood spontaneously.

98. Conduits.—There are two types of wooden conduit on the market, both of which are very good for insulating steam pipes placed underground.

99. The **Wyekoff covering,** shown in Fig. 49 (*a*), is built of wooden staves in two layers, as *a* and *b*, inside of

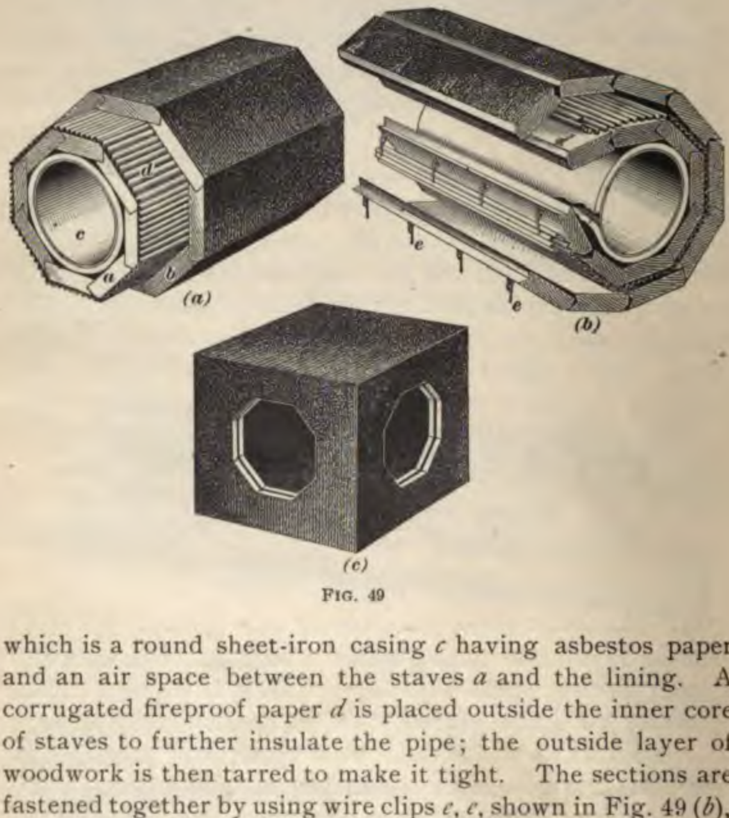


FIG. 49

which is a round sheet-iron casing *c* having asbestos paper and an air space between the staves *a* and the lining. A corrugated fireproof paper *d* is placed outside the inner core of staves to further insulate the pipe; the outside layer of woodwork is then tarred to make it tight. The sections are fastened together by using wire clips *e*, *e*, shown in Fig. 49 (*b*), which shows the conduit partially opened. The ends and

fittings are incased in a cube-shaped box, as illustrated in Fig. 49 (*c*). Tests made of the above covering show it to effect a considerable reduction of condensation.

100. Fig. 50 shows another type of wood-stave covering, which in the small sizes consists of logs of wood bored out, and in the larger sizes is built up, of segments, into a round tube, which is provided with an inner core *a* of sheet iron with asbestos outside of the iron. The wood is subjected to a creosoting bath under high pressure, which preserves it and makes it a very satisfactory casing for use underground. The pipe is usually placed in the wooden tube on expansion rollers, which keep it about concentric, allowing an air space all around the pipe. The ends of the conduit are sealed at the junction boxes, where fittings are placed, and made tight with iron collars fitting the pipe. Junction boxes can be built of wood for use with this pipe; in some of the places where it has been used, brick junction boxes have been provided. When the pipe is laid, it is coated with hot tar in order to tightly seal all the joints, which are made by forming a recess on one end of the pipe and a corresponding cylindrical projection on the other end, thus making the so-called **socket-and-spigot joint.**

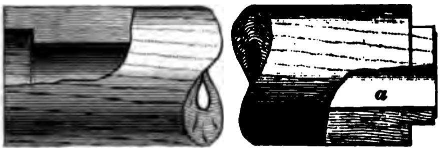


FIG. 50

SHEET COVERINGS

101. Sheet coverings are used to incase large pipes, smoke pipes, boiler domes, shells of boilers, tanks, etc., and are usually made in convenient shapes, so that any curved or flat surfaces can readily be covered.

102. The **Asbestos air-cell covering,** shown in Fig. 51, is light in weight and is easily applied, as it is made of layers of corrugated paper fastened with silicate of soda, and can

be sawed like wood. The edges are usually pasted over with a paper tape to prevent circulation of air through the

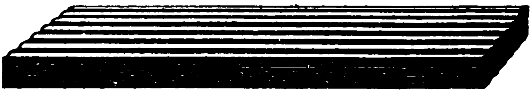


FIG. 51

corrugations, and the board can be nailed to wooden surfaces, or secured with small metal studs, or angles, and wire, depending on the conditions.

103. The **Nonpareil cork fireboard** is a very good insulator, but not quite as fire-resisting as the asbestos air-cell covering. It can be easily cut by sawing, and can be had in blocks to suit the conditions. The joints are usually cemented with a plastic cement, in which cork forms the body.

104. **Magnesia sectional blocks** can be secured to surfaces in any convenient manner; this covering is absolutely fireproof, and gives a first-class insulation.

105. Other makes of insulating blocks consist of asbestos, asbestos and sponge combined, asbestos and magnesia, asbestos and fibrous grass, cocoa fiber, hair, excelsior, etc., combined with plaster to form a body; they are used for the same purposes as those previously mentioned. Some of these coverings are very good insulators.

FLEXIBLE COVERINGS

106. One form of a flexible covering is **asbestos paper** made similar to asbestos pipe covering, but not as rigidly cemented. **Fire-felt** is a fine fibrous asbestos formed into a flexible felt-like sheet; it can be applied in the same manner as common hair felt and is finished by sewing canvas over it. It is a first-class covering, used as a substitute for hair felt on irregular surfaces.

107. **Hair felt** is made in various thicknesses, and usually comes in bales of a size convenient to handle, and

TABLE II

FELT COVERING REQUIRED FOR STEAM PIPES

Size of Pipe	¾-Inch. Square Feet	1-Inch. Square Feet	1¼-Inch. Square Feet	1½-Inch. Square Feet	2-Inch. Square Feet	2½-Inch. Square Feet	3-Inch. Square Feet	3½-Inch. Square Feet	4-Inch Square Feet	5-Inch. Square Feet	6-Inch. Square Feet	7-Inch. Square Feet
Asbestos paper, 2 layers	.60	.65	.85	1.04	1.30	1.47	1.80	2.08	2.32	2.90	3.46	3.95
Hair felt, 1 inch, 1 layer	.75	.90	1.00	1.04	1.13	1.26	1.42	1.55	1.68	2.00	2.27	2.53
Rosin-sized paper, 1 layer	.80	.95	1.05	1.09	1.18	1.30	1.46	1.60	1.72	2.05	2.32	2.60
Canvas, 1 layer	.90	1.10	1.14	1.20	1.30	1.43	1.58	1.70	1.85	2.15	2.44	2.70

is made 2 yards wide. It is used as a cheap pipe or surface covering where the saving of heat is a greater consideration than length of service. It absorbs moisture easily, and where alternately wet and dry and subjected to high temperatures disintegrates very soon. It is also very objectionable in that it forms a lodging place for vermin and mice.

108. The usual method of covering piping with felt is to place two layers of asbestos paper, of a thickness giving about 10 square feet to the pound, around the pipe and then to wrap with one layer of 1-inch hair felt, and outside of this one layer of plain building paper, or rosin-sized paper, finally wrapping with twine and sewing canvas over it.

109. The amount of material in square feet required per lineal foot of pipe is given in the table on this page.

One ball of twine will be required for sewing each 100 feet; 1 pound of beeswax will be required for each 300 feet of twine used.

PLASTIC COVERINGS

110. There are in the market several **plastic cements** that are composed of the same combination of materials used for sectional pipe coverings, and that are used for the same purpose. Coverings of plastic cement are generally finished by sewing canvas over them, which holds the cement in place in case it cracks. Plastic coverings may also be used for a finishing coat to be placed on top of the paper covering.

111. Plastic covering is applied either directly to the surface to be protected, or to a framework of metal lathing, which is kept clear of the heated surface by angle irons, thimbles, wire rods, or in any other convenient manner. In either case, a light rough covering is applied first, which is wrapped with wire or covered with wire netting. The hard finishing coat is then applied on top and smoothed down. For a final finish the last coat may be painted, but it is preferable to place canvas over it. A neat finish is given by thin brass bands placed over the canvas at regular intervals. When the plastic covering is applied to a framework of metal lathing, a dead air space is formed, which greatly increases the protective value of the covering. Incidentally, it may be mentioned that an air space is of value in preventing radiation of heat from a surface protected by it, only in case there is no circulation of air in it, which means that the air space must be entirely closed or **dead,** as it is called.

LOOSE FIBROUS INSULATIONS

112. **Loose asbestos** can be bought in bags; it is used for filling in around pipes in trenches, or below the lagging of cylinders. It is also used in buildings for deadening sound, and for protection against the weather or dampness. Besides asbestos, **mineral wool,** which is a fibrous feather-like wool made from the slag of the iron furnace and limestone, is used; it has a large percentage of iron in its composition, and contains sulphur. Another form of wool,

similar in most respects to mineral wool made from slag, is blown from granite; it contains less oxide of iron and little sulphur. Its chief constituent is lime, and it can be used for filling trenches, covering pipe placed in exposed places, for deadening sounds by being placed inside of walls, and similar purposes.

TESTS OF PIPE COVERINGS

113. Professor Charles L. Norton, of Boston, made some very interesting tests of a number of coverings for use with steam at 10 pounds, and at 200 pounds pressure per square inch, the tests being made by electricity at the temperatures due to the above-named pressures; this method of testing was as fair as could be wished, as the temperature within the tube tested was maintained constant, and the exterior conditions were as nearly constant as a closed room could be made to prevent air currents.

114. The test apparatus consisted of a 4-inch tube 18 inches in length, into which was introduced, concentric with it, another tube of copper, around which was wound the heating coil in the form of a helix, and which was connected with the current through a wattmeter, an ammeter, and a voltmeter, showing the current consumed, while thermometers showed the internal temperature of the tube, and that of the outside air. The tube was filled with oil, and a spiral agitator was introduced into the core of the copper tube, to insure a circulation of the oil to all parts of the 4-inch pipe. Each piece of covering tested was placed under the same conditions, and identical observations were made in each case; the results are given in Table III.

115. Pipe laid in wooden boxing, but not exposed to dampness, has also been tested by Professor Norton, who used a wooden box nailed tight, made from $\frac{7}{8}$-inch pine, 1 inch larger than the pipe all around, and filled with various substances, which showed the following losses per square foot per minute, at a temperature corresponding to 200 pounds

TABLE III

TEST OF PIPE COVERINGS

	Thickness. Inches	B. T. U. Loss per Square Foot of Surface Per Minute	Per Cent., or Ratio of Loss in Covering Compared With Bare Pipe	Average Weight of Covering, in Ounces, for 4-Inch Covering
Nonpareil cork, Standard	1.00	2.20	15.9	27
Nonpareil cork, octagon low-pressure	.80	2.38	17.2	16
Manville high-pressure	1.25	2.38	17.2	54
Magnesia, 85 per cent	1.12	2.45	17.7	35
Imperial	1.12	2.49	18.0	45
Asbestos air cell	1.12	2.77	20.0	35
Infusorial earth	1.50	2.80	20.2	
Magnasbestos	1.12	2.91	21.0	48
Calcite	1.12	3.61	26.1	66
Bare pipe		13.84	100.0	

per square inch steam pressure, with the surrounding air at a temperature of about 70° F. The result of these tests is given in Table IV.

TABLE IV

TESTS OF RADIATION LOSSES IN WOODEN BOXES

Name of Covering	Radiation Loss in B. T. U. Per Square Foot Per Minute
Box with sand	3.18
Box with granulated cork	1.75
Box with cork and infusorial earth	1.90
Box with sawdust	2.15
Box with charcoal	2.00
Box with ashes	2.46
Box with closed air space only	3.56

116. Wooden staves 1 inch thick secured to the pipe, with joints made tight, show a radiation loss of from 3.4 to 3.7 B. T. U. per square foot per minute; with staves 2 inches thick it varies from 2.31 to 2.5 B. T. U. These values hold only for wooden covering made air-tight at the joints and kept perfectly dry and in still air. When air-currents impinge on the wood, the radiation losses will be higher.

RADIATORS AND COILS

RADIATORS

DIRECT RADIATORS

GENERAL CLASSIFICATION

1. Radiators are metallic bodies so constructed that a large amount of surface is obtained. They are used for warming buildings by emitting heat to the air in the buildings, or to air as it enters buildings. Steam or hot water inside the radiator heats it, which in turn heats the air and other matter surrounding it.

Radiators made of cast iron are known simply as radiators; those made of iron pipe and fittings are called **coils**.

There is a large number of different kinds and styles of radiators manufactured, but they differ chiefly in arrangement and ornamentation. In a general way they may be classified as *direct radiators; indirect radiators*, and *direct-indirect* or *semi-direct, radiators.* Nearly all radiators are made of cast-iron sections screwed or bolted together, while nearly all coils are made of wrought-iron or steel pipes screwed into suitable fittings or manifolds.

LOCATION

2. Introduction.—**Direct radiators** are located inside the rooms or other places to be warmed, and usually stand on the floor. The air in a room that is warmed by direct radiation is therefore reheated and circulated within the

room unless special provision is made for changing the air. The proper place to locate a direct radiator is at the coldest place in the room to be warmed. Ordinarily this is under a window at the north or northwest side of the building. Cold winds usually blow in through the crevices of such a window and will make a room uncomfortably cold near the window even though it is comfortably warm elsewhere. If the radiators are located so that the warm-air currents ascending from them will mix with the incoming cold-air leakage, a nearly uniform temperature can then be maintained in the rooms.

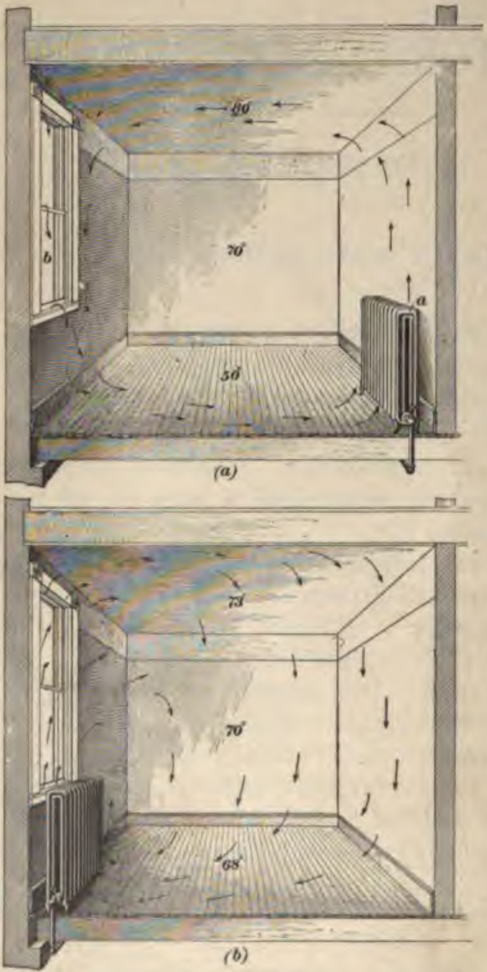


FIG. 1

3. Examples of Location.—Fig. 1 shows two different locations for direct radiators in a room, and the air-currents produced by heat from the radiators. In Fig. 1 (*a*) the radiator *a* is shown located against the inner wall. Air cooled by the window *b*, and aided by cold-air leakage, falls to the floor, then flows

slowly toward the radiator, where it becomes heated, and rises to the ceiling. This produces a circulation in the direction shown by the arrows, the hot air being at the ceiling and cold air on the floor, while 70° may obtain in the middle of the room. This is considered bad practice and should be avoided.

In Fig. 1 (*b*) the radiator is shown located under the window. The rising current of warm air, mixing with the cold air falling from the window, not only prevents the cold air from gathering on the floor, but also produces a lower temperature at the ceiling and a higher temperature at the floor. The temperatures marked in these illustrations are not constant; they change with changing conditions.

If a radiator is located in the center of a room the cold air on the floor will travel from all directions toward the radiator, where it will become heated and ascend to the ceiling in the form of a column; the resultant temperatures at floor and ceiling will be similar to those obtained by the system shown in Fig. 1 (*a*).

SIZE OF A RADIATOR

4. Designation.—The amount of exterior surface on the radiator designates the size of the radiator. Thus, a 100-square-foot radiator has 100 square feet of outside surface exposed to the air.

5. Dimensions of Sections.—The dimensions of the sections of radiators vary with different manufacturers. Cast-iron radiators are constructed of sections that vary in shape, size, and ornamentation, according to the manufacturers' ideas. The favorite form of section is a hollow loop, a number of which when connected together at the base, sometimes also at the top, constitute the radiator. Short sections are used for making low radiators; long sections are employed for making high radiators. The standard height of a section is 38 inches above the floor, and manufacturers usually ship radiators of this height if the height

is not mentioned in the order. Ordinarily one section of a two-column loop radiator 38 inches high has 4 square feet of heating surface, that is, outside surface.

There are a number of radiator sections on the market that contain more than 4 feet to a standard section. Some of these have extended surfaces, which form flues, in the heart of the radiators.

NIPPLE CONNECTIONS

6. **Push-Nipple Joints.**—There are two kinds of nipples used for connecting radiator sections, namely, **slip nipples,** also called **push nipples,** and **screw nipples.** When push nipples are used the sections are connected at the bottom with a steel nipple, made with a slight taper that fits into tapered openings machined in each section of the radiator; the sections are then bound together by a long iron rod that passes through cored openings in each section, and is secured at each end by a thread and nut.

Top and bottom connections are made to allow water circulation, and are used chiefly for hot-water systems. The top ends of the steam-radiator sections are usually not connected by nipples, but are merely held in position by lugs that dovetail into one another, a bolt being passed through the sections to draw the tops together. The end sections are tapped with screw threads to suit the pipe connections.

7. **Screw-Nipple Joints.**—Screw-nipple joints are frequently made by screwing up the sections on the nipples. Right-and-left screw-nipple joints are made by screwing up the nipples. Radiators with screw-nipple joints are built up by screwing on one section at a time.

TYPES OF DIRECT RADIATORS

8. **Operation.**—Direct radiators give off heat by radiation to all surfaces that absorb the rays. The concealed, or flue, surfaces, that are masked by adjoining surfaces, give

off heat by convection only. Radiators having the greatest exposed surfaces on the outside are usually considered to be best for direct radiators, and those exposing the greater amount of surface to the air passing through them are considered better for indirect heating. A combination of the two is used very advantageously for admitting fresh air for supplying ventilation by **direct-indirect radiation.** The heaters that are placed in casings, where there is no chance of radiant heat being given off, are called **indirect radiators.**

9. Single-Column Radiators.—A single-column radiator is shown in elevation at (*a*), in end view at (*b*), and in section at (*c*), in Fig. 2. It is called a **single-column radiator** to distinguish it from the regular two-column radiator in common use, the chief difference between them being that the single-column radiator is only about 4½ inches wide, while the two-column radiator is about 7½ inches wide. This radiator, being narrow, is especially suited for use in narrow halls or passages where a wide radiator would be an obstruction. It presents a large amount of exposed surface and is consequently an efficient heater.

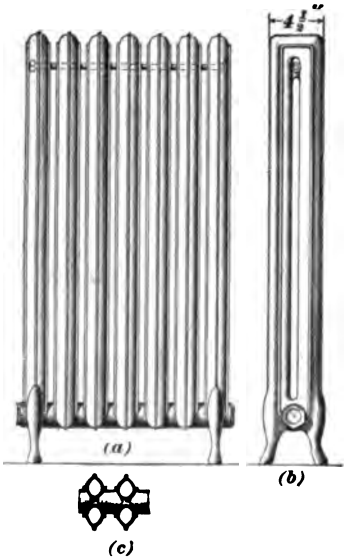


Fig. 2

It is not suited for general use, because the radiator must be long in order that it shall contain a sufficient number of square feet of heating surface.

10. Two-Column Radiators.—Two-column radiators are similar to the single-column radiators, except that they

are wider, and each section consequently has a greater exposed surface. The width is usually about $7\frac{1}{2}$ inches and the spread of the legs about $8\frac{1}{2}$ inches. Fig. 3 (*a*) shows the general appearance of a two-column radiator, which is built up of two end sections, one of which is illustrated in Fig. 3 (*b*), and a sufficient number of inside or intermediate sections, one of which is shown in Fig. 3 (*c*). The size of the radiator is increased or decreased by adding or removing

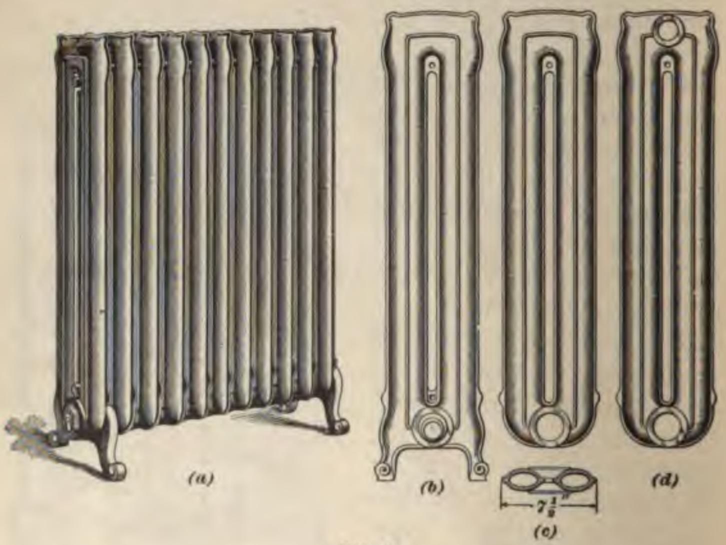


FIG. 3

intermediate sections. The section illustrated in Fig. 3 (*c*) is known as a **steam intermediate section.** In order to make a radiator suitable for hot-water heating, a **water intermediate section** is made with a special tapping on top, as shown in Fig. 3 (*d*), which allows the sections to be connected together on top as well as on the bottom to insure a circulation of the hot water.

11. Three-Column Radiators.—Fig. 4 shows a horizontal section of a three-column radiator. This is much

wider than the ordinary two-column radiator, being about

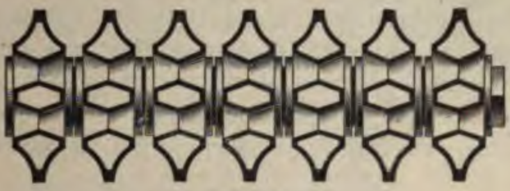


FIG. 4

10 inches wide. Each section usually contains about 5 or 6 square feet.

12. Four-Column Radiators.—Fig. 5 shows a four-column radiator of standard height. Each section is $10\frac{1}{2}$ inches wide, the width of the legs being about 11 inches. Each standard section contains about 8 square feet of surface. Radiators of this class are suitable for places where long radiators cannot be installed, but the surfaces of the inside columns are inefficient unless they are constructed so that a good upward circulation of air is obtained through the radiator. These inside surfaces enclosed by the outer columns do not warm the building by radiation, but by convection; hence, the necessity of large openings between the columns. Ordinarily it is considered advisable to avoid three-column and four-column radiators as much as possible and use the two-column radiator instead, in which radiator all the heating surface has a high heating efficiency.

FIG. 5

13. Flue Radiators.—Fig. 6 (*a*) shows an end or steam-leg section, and Fig. 6 (*b*) an inside or intermediate section,

of a steam radiator of the flue type. A sectional view of the radiator sections placed together is shown in Fig. 6 (*c*). When the sections are placed together, the front edges nearly, but not quite, touch one another, and a number of flues are formed by vertical ribs *a* cast on each side of the inner sections and on the inner cheek of the end section. The sections are cast in the form of hollow boxes with flat

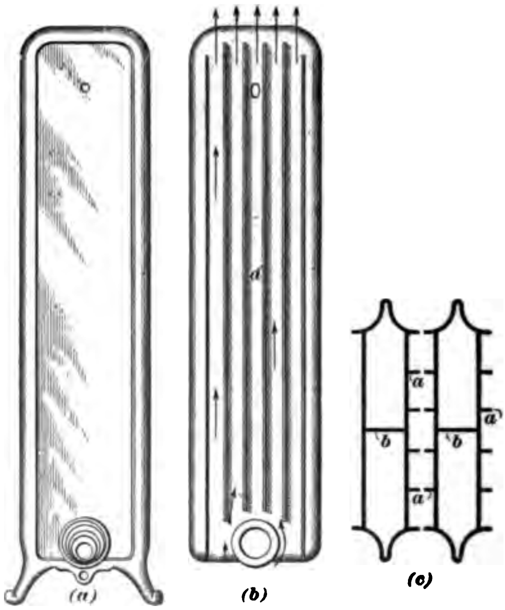


FIG. 6

cheeks, and therefore cannot resist a high pressure, even though the cheeks may be tied together by a partition *b*. This form of radiator is more efficient in the low size than in the high size. There are other designs of flue radiators on the market, but they all operate to heat the air in substantially the same manner, that is, by inside flues.

14. Dining-Room Radiators.—Fig. 7 shows a special dining-room radiator containing a warming closet set on

top of a number of low sections *a*, and provided with shelves inside. This warming closet, which is made of cast iron, is used for warming plates and keeping food warm. The sections on each side of the closet are 38 inches high. The

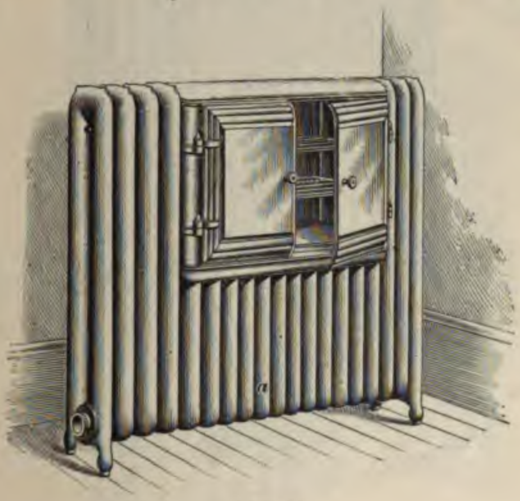


FIG. 7

oven usually contains three shelves, or racks, each about 25 inches long by 12 inches wide, with an 8-inch or 10-inch space between them. Some dining-room radiators are equipped with an extra warming closet that extends down to the radiator base.

15. Corner Radiators.—Generally speaking, it is not advisable to install corner radiators, but occasionally it is actually necessary to use them. Heating surface in a corner radiator is not so cheap as that in straight radiator form, because special castings are required in a corner.

Fig. 8 (*a*) shows a corner radiator connected up complete in the corner of the room. A plan of the corner sections is shown in Fig. 8 (*b*). The central corner section *a* is provided with feet, and the other corner sections *b* and *c*, as well as *a*, have inclined sockets, as at *d*, which are tapped

so as to permit ordinary straight nipples to be used. As

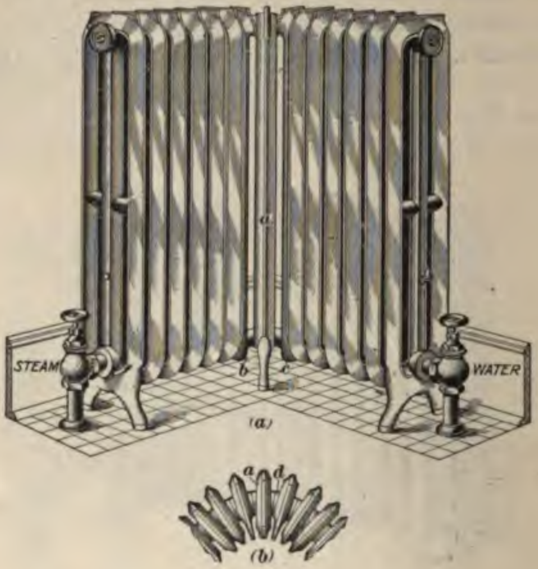


FIG. 8

corner radiators are usually large, it is often necessary to connect them with two valves, as shown.

16. Window Radiators.—It has been stated previously that the proper place to locate a radiator is under a window. Therefore, low radiators are commonly used. When it is necessary, however, to place a larger amount of radiation near the window than can be obtained from a low radiator, it is necessary to make the radiator both of low and high sections, as shown in Fig. 9, the high section being located on each side of the window. Radiators of this description are particularly suited to places where curtains and window draperies will not be used.

Another form of window radiator is that in which the high sections come between two windows and low sections come under the windows. The radiator shown in Fig. 9 is best adapted to cases where there is but one window

in the room. When two windows are near each other, tall sections may, however, be placed between the windows,

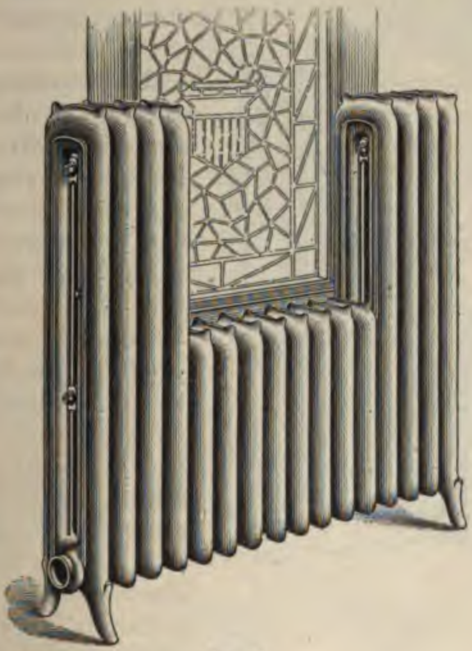


FIG. 9

and the low sections under the windows. This makes a symmetrical radiator.

17. Stairway Radiators.—Occasionally it is necessary to place a radiator against the stairs, where an ordinary radiator would not be in keeping with the surroundings. A specially constructed radiator is commonly used for such cases. It should be built from sections of different heights, as shown in Fig. 10, the number of sections of the same height being determined by the inclination of the steps. When ordering such radiators, it is advisable to send to the radiator manufacturer a drawing of the radiator desired, stating the number of square feet of radiation required and

giving the pitch of the stairs. The manufacturer then makes the radiator in accordance with the drawing and description.

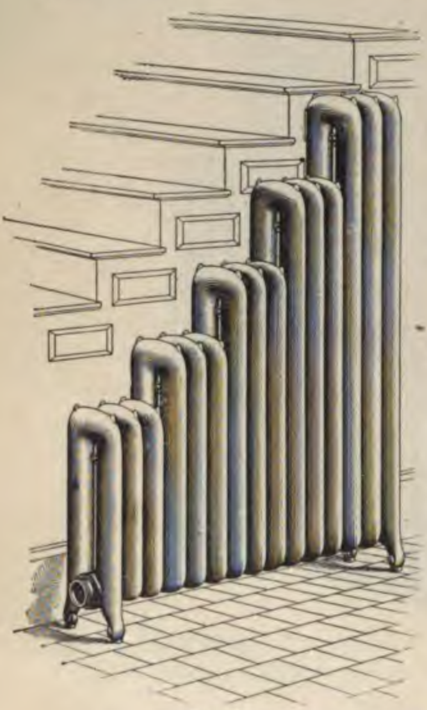


FIG. 10

18. Circular Radiators. — Circular radiators are formed from vertical loops by having the base of each loop tapering, so that a number of the sections when set together will form a circle. The angle of the taper will depend on the diameter of the circle desired. The manufacturers of radiators have patterns to suit different circles. Circular radiators having a cast-iron base are made any diameter desired. The base section is cast the desired diameter, and the vertical tubes are screwed into the base section. The center space of circular radiators is usually left open and forms a vertical flue. Circular radiators that are put together in one piece are connected up in the same manner as ordinary radiators. If they are put up in two pieces, they are composed of two radiators, each having the form of a half circle, which, when bolted together, constitute a circular radiator. Each half is then piped separately.

Circular radiators for steam are made in different heights, such, for example, as 45 inches, 38 inches, 32 inches, 26 inches, 23 inches, and 20 inches high above the floor. Unless otherwise ordered, circular radiators are usually tapped for the supply pipe in front, and for the return pipe at the back, of both halves. If the circular radiator is in one

piece, it is usually tapped for supply and return connections in front, so that the steam circulates all around the radiator.

19. Column Loop Radiators.—Column loop radiators require to be made in halves, in order that they may be placed around columns; they are then bolted together. They can be obtained in different heights. Column radiators composed of a cast-iron base box, with tubes or loops screwed in on top to form the radiator surfaces, may or may not have a continuous base; that is, the radiator may or may not be in one piece when bolted together around the column. Best practice calls for separate base boxes, that is, two separate radiators bolted together and piped independently. This avoids the use of flanged joints between the halves of the base, and thus prevents liability of leakage.

20. Wall Radiators.—Wall radiators are long narrow radiators that are attached to the walls. They extend over a large area, and being placed on the outer walls constitute an excellent mode of distributing radiating surface. Ordinary radiators have the surfaces bunched, and the heat emitted from them is consequently localized, while the heat

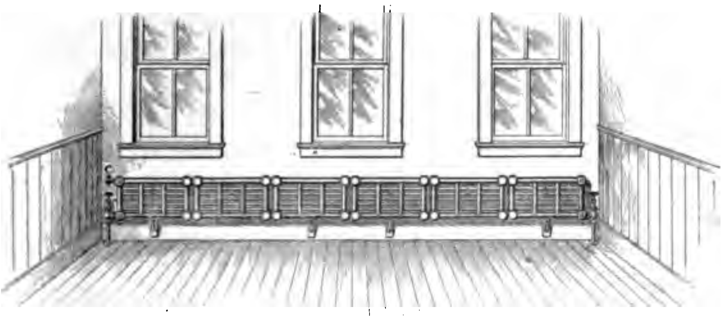


FIG. 11

emitted from wall radiators is more uniformly distributed through the room. Fig. 11 shows a wall radiator composed of a number of sections connected together in a long line with radiator nipples at the top and bottom of each section, and supported on suitable brackets, firmly attached to the

wall by expansion bolts. The steam enters one end through the inlet valve, travels the full length of the radiator, and the water of condensation escapes through the return valve, the air vent being located at *c*.

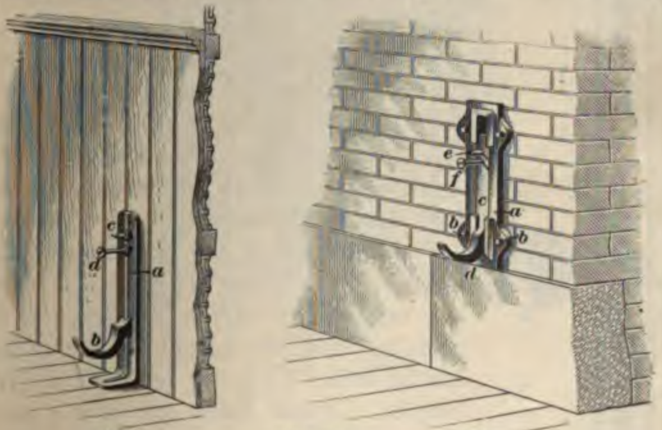
These wall radiators can be made up so that the sections will be either vertical or horizontal, according to the length or height of the radiator desired. The radiator shown is known as the *Fowler*. There are three sizes of section. The **standard size** is 24 inches long, 12½ inches wide, about 3 inches thick, and contains 7 square feet of radiating surface. The **medium size** is 21 inches long, 12½ inches wide, about 3 inches thick, and contains 6 square feet of radiating surface. The **short size** is 17 inches long, 12½ inches wide, about 3 inches thick, and contains 5 square feet of radiating surface. Wall radiators of the form shown can be used in place of wrought-iron pipe coils, and can be fastened to walls and ceilings, with the sections extended or grouped together. The construction of the sections permits a number of combinations. The sections are put together by radiator nipples, which are screwed up from the inside by a long bar with a square end that engages projections inside the nipples.

21. It is not advisable to make wall radiators very long, because then the weight of the sections strains the nipples by subjecting them to tension, and makes them liable to crack and leak. Instead of using one very long wall radiator, it is better to use several smaller ones. Other forms of radiators, such as single-column radiators, can be attached to walls by iron brackets, but they have the disadvantage of concentrating the radiating surface, while the special wall radiator distributes it.

22. Wall radiator supports are shown in Fig. 12; they are suited to the class of radiators shown in Fig. 11. In Fig. 12 (*a*) the support *a* is attached to a wainscoted wall by 2-inch or 2½-inch screws. The radiator is set in the hook *b* which projects from the hook plate. The upper tube of the radiator rests against a distance piece *c*, and is held firmly in place by the bolt *d*. This form of hook plate is

extended to the floor and provided with a duck foot, so that the floor takes the weight of the radiator, the screws being used only to hold the plate against the wall. Supports of this character are quite suitable for wall radiators with flexible connections, and are commonly used. But, should occasion arise when a rigid connection must be made between a riser and the wall radiator, a special support should be employed to allow the end of the radiator to move with the expansion of the line. Of course, this is not desirable, and should be avoided as much as possible, but sometimes existing conditions require such a connection.

A sliding wall support, such as is used in the printery of the International Textbook Company, is shown in Fig. 12 (*b*).



(*a*) FIG. 12 (*b*)

It is attached to a pressed mottled brick wall. A cast malleable frame *a* is set on a stone base, the frame being secured to the brickwork by four 4-inch expansion bolts *b*, *b*. The hook plate *c* is held against the wall by the frame and is free to slide up and down under expansion or contraction of the riser, without the actual strength of the support being affected or the bolts loosened. The radiator rests on the hook *d* and is held tightly against the distance piece *e* by a screw *f*. Another advantage of this hanger is that either end of the radiator can be raised by inserting a piece of iron

under the plate *c*, which is often desirable to ensure good drainage of the radiator.

23. Box Base Radiators.—Radiators that require a hollow cast-iron box for the base, and that are sometimes called **column base radiators** instead of **box base radiators**, are constructed in different ways. The most common types are the *Bundy* and the *Nason*.

24. The **Bundy radiator** is made in many forms, the distinguishing feature being the use of a column known as the **Bundy loop.** Fig. 13 shows at *A* a longitudinal section of a Bundy loop, and at *B* a cross-section. A number of these loops screwed into a cast-iron radiator base of suitable shape constitute the radiator. The Bundy loop is also used for extending the heating surface in some hot-water heaters. Air does not stay in the loop, but being heavier than steam falls into the base by gravity.

FIG. 13

Bundy loop radiators are made with two sizes of loops, which are the standard size loop and the large loop. Each loop is screwed into the base. The bases are tapped for steam and return connections, and the height of the radiator can be varied by using loops of different lengths. These loops are made in various heights, so that radiators can be built from 12 inches to 45 inches high. The standard dimension loop is usually made up into radiators 42 inches, 36 inches, 30 inches, 24 inches, and 18 inches high. Radiators ordered to heights differing from these are specials, and they cost about the same as the next higher height. For instance, a 32-inch radiator would probably be billed at 36-inch price. Hence, the advisability of ordering radiators according to manufacturers' standard list of heights.

25. Fig. 14 shows a Bundy steam radiator composed of one row of Bundy loops *a*, *a*, etc., screwed into a cast-iron base *b*, and provided with a grilled top in order to make a neat finish. This radiator presents all its surface in a single row of loops as a direct radiating surface, but the two-, three-, and four-row radiators of this type have a large percentage of the surface that is masked by the outer loops,

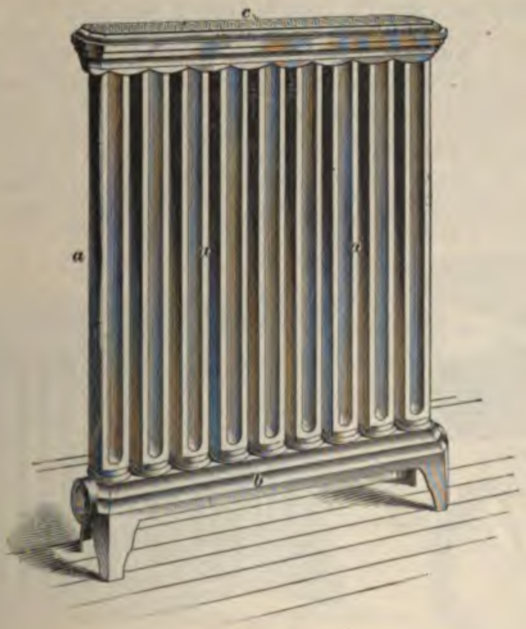


FIG. 14

which prevent the direct radiation from them. Therefore, each of the bases for the wider radiators is pierced by openings that permit air to flow through the base and pass up between the concealed loops of the radiator. This warm air escapes into the room through the top and thus transmits heat from the inner loops to the room by convection.

26. The bases of Bundy radiators can be purchased tapped for both steam and return connections at one end, or at opposite ends, as desired.

The widths of the bases are about as follows:

Single-row........................	$5\frac{1}{2}$ inches
Double-row........................	$9\frac{3}{4}$ inches
Three-row	$13\frac{1}{2}$ inches
Four-row	$17\frac{1}{2}$ inches

One lineal foot of the standard size Bundy loop contains 1 square foot of surface, and 1 lineal foot of the large or special loop contains $1\frac{1}{8}$ square feet of surface.

27. The **Nason tube radiator,** like the Bundy radiator, is composed of a cast-iron base box surmounted by circulating tubes. Fig. 15 (*a*) shows a Nason tube. It is connected to the radiator base by a screw joint, and is divided in two passages by means of the sheet-iron plate or diaphragm *a*, which extends nearly to the top of the tube. This tube is

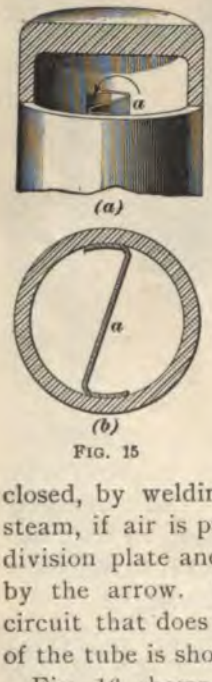


FIG. 15

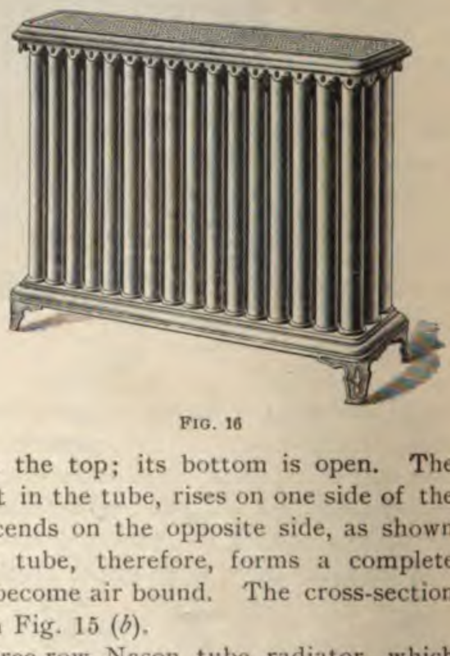


FIG. 16

closed, by welding, at the top; its bottom is open. The steam, if air is present in the tube, rises on one side of the division plate and descends on the opposite side, as shown by the arrow. Each tube, therefore, forms a complete circuit that does not become air bound. The cross-section of the tube is shown in Fig. 15 (*b*).

Fig. 16 shows a three-row Nason tube radiator, which in construction is similar to the Bundy, except that the

Nason tubes are used instead of the Bundy loops. The Nason tube is a 1-inch wrought-iron pipe.

28. The original Nason radiator has a hollow base without any perforations. The improved Nason radiator, however, usually has a base constructed with vertical air holes through it, so as to admit air through the spaces between each of the pipes. These holes are circular and made slightly conical in form, so that each is in fact a small blowpipe that directs a current of cold air, taken from the floor, between the pipes, and increases the rapidity of circulation through the body of the radiator. This is particularly valuable in radiators more than two columns wide. In ordering such radiators, the improved form should be mentioned. These radiators are tested under a pressure of 70 pounds. Special radiators are made to stand higher pressures.

The standard Nason tube has 1 square foot of surface, and the heating surface is increased or diminished by varying the length of the tubes. The usual height of a Nason improved radiator is 35 inches. The outside width of the base at the floor is as follows: single-row, 5½ inches; two-row, 7½ inches; three-row, 9½ inches; four-row, 11¼ inches. The usual height from the center of the tapping to the floor is 3¾ inches.

29. Window-Seat Radiators.—Steam fitters are occasionally called on to place radiators underneath seats in tower and bay windows. The ordinary design of flue radiator is not desirable for this purpose, because the seats usually are placed so close to the top of the radiator that the warm air is boxed in, so to speak, and cannot escape into the rooms. Fig. 17 shows a special window-seat radiator in position. It is composed of a number of cast-iron sections connected by nipples. Flues are formed between the sections, by curved fins placed on both sides of the sections, as shown. Air enters the curved flues at the bottom of the radiator and is ejected from the face of the radiator, and

thus enters the room. The standard height of this radiator is 14 inches; depth, 13 inches; distance between center to center of the sections, 3 inches. In arranging a seat over a low radiator, it is advisable to insulate the under side of the seat with asbestos, and to keep the seat away from the wall 1 or 2 inches, so that warm air may escape up the back wall and thus counteract the cold air falling from the windows.

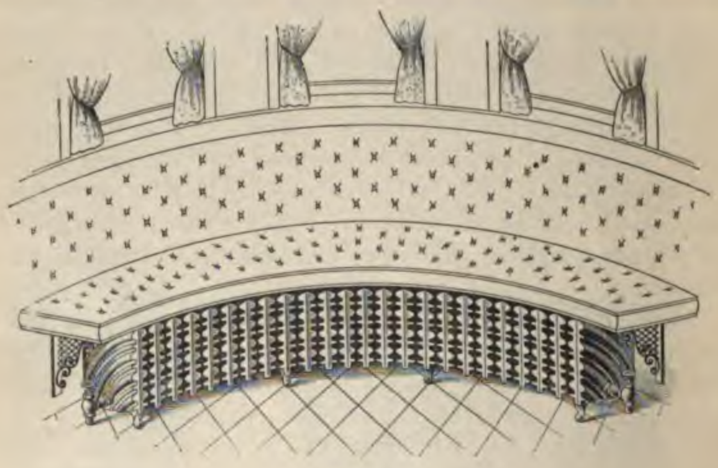


FIG. 17

The radiator shown in Fig. 17 is adapted for steam or water, because it is connected by nipples at both top and bottom, and is tapped at both ends. For window radiators, hot water is most suitable, because a medium temperature can be employed. A steam radiator generally makes the seat uncomfortably warm.

RADIATOR TAPPINGS

30. Standard Sizes.—It is customary for radiator manufacturers to tap their radiators in accordance with a tapping list; radiators are furnished tapped according to this list unless otherwise ordered. The size of the tapping commonly employed for loop radiators is given in Table I.

TABLE I

RADIATOR TAPPING LIST

Kind of Radiator	Size of Radiator Square Feet	Tapping Inches	
		Supply	Return
Steam radiator, one-pipe system....	Up to 24	1	
Steam radiator, one-pipe system....	Above 24 to 60	1¼	
Steam radiator, one-pipe system....	Above 60 to 100	1½	
Steam radiator, one-pipe system....	Above 100	2	
Steam radiator, two-pipe system....	Up to 48	1	¾
Steam radiator, two-pipe system....	Above 48 to 96	1¼	1
Steam radiator, two-pipe system....	Above 96	1½	1¼
Hot-water radiator..................	Up to 40	1	1
Hot-water radiator..................	Above 40 to 72	1¼	1¼
Hot-water radiator..................	Above 72	1½	1½

31. Special Tappings.—If tappings different from those given in Table I are desired, they must be specified in the order. All air-valve tappings are made ⅛-inch by the manufacturer; if other sizes are required, they must be ordered specially. Both the supply and return legs of the loop radiators usually have air-valve tappings with interchangeable plugs. Special tappings for supply and return at the bottom of the same end of a radiator are usually made 2-inch, and are bushed according to the tapping list. Special tappings for top supply and bottom return at the same end are usually furnished 2-inch and bushed down according to the tapping list. Tappings in other positions can be also obtained if the order is accompanied by a sketch showing the size and location of the tappings.

SPECIAL RADIATOR SUPPORTS

32. Duck-Foot Legs.—One of the principal objections to radiators standing on the floor is that carpets cannot be conveniently laid without cutting and fitting them around

the radiator feet, unless the radiators are disconnected in order to lay or remove the carpets. To avoid this trouble, the end sections of some radiators are cast in the form shown in Fig. 18. Instead of the sections being provided with two feet, each radiator and section is supported on one foot *a*, made as shown in the figure. The carpet is laid over the foot, and can be lifted and relaid conveniently without disturbing the radiator. The same thing is accomplished by the use of detachable feet.

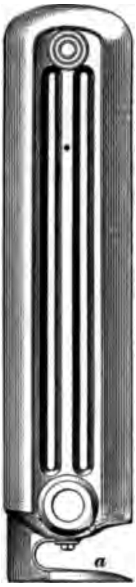


FIG. 18

33. Pedestals.—Occasionally it is necessary to raise a radiator off the floor in order to secure sufficient height to allow the water of condensation to flow freely out of the radiator by gravity. Pedestals are used for this purpose. They can be purchased from the manufacturers in heights varying from $\frac{1}{4}$ inch to 9 inches. Pedestals should be avoided, if possible, because the expansion of the lines sometimes raises radiators so that the pedestals become loose, removed, and lost.

RADIATOR TOPS

34. Radiator tops are perforated or solid slabs or plates placed on the tops of radiators, either to improve their appearance or their utility. Ordinarily, loop radiators should not be provided with tops, because their appearance is not sufficiently improved to counterbalance the loss of heating efficiency due to obstructing the rising currents of warm air. The higher the velocity of air traveling between the surfaces of the radiator, the more efficient is the radiator as a heater. It is customary to avoid the use of tops on the loop radiators. They are used, however, extensively on radiators of the Bundy loop and the Nason tube patterns,

to make a neat finish. Solid radiator tops, such as marble slabs, should not be used unless there is a surplus of radiation in the room to compensate for the loss due to the use of such tops.

DIRECT-INDIRECT RADIATORS

INTRODUCTION

35. **Direct-indirect radiators,** or **semidirect radiators,** as they are very often called, are placed and connected up inside the rooms to be warmed by them in the same manner as direct radiators, except that special connections are made by which fresh air from the outer atmosphere is permitted to flow between the heating surfaces of direct-indirect radiators and enter the rooms warm. Direct-indirect radiators, therefore, have the advantage of ventilating the building as well as warming it by direct radiation They are usually located against the outer walls, being generally placed underneath windows; the air supply is brought in through the walls. If they are located against the inner walls, special sheet-metal ducts may be used to supply them with fresh air from the outer atmosphere.

DETAILS OF INSTALLATION

36. **Construction of Radiator.**—A **prime surface direct-indirect radiator** is shown in Fig. 19. It is a simple two-column Bundy radiator having the base enclosed by plates *a*, which compel the fresh air that comes in through the flue *b* to pass upwards between the hot radiator loops before it can escape into the room. The air is thus warmed as it enters the room. Fig. 20 shows in section a direct-indirect flue radiator in position. Air from the outer atmosphere flows in through the wall box provided at *a* with plates called **louvre plates,** to keep out the rain and snow.

The space between the joists is closed off with a board *b*, so that the air is compelled to rise through the hole in the floor at *c*, and pass up through the flues *d* of the radiator, as shown by the arrows. The base box, located under the radiator, is furnished with a valve or damper made in two halves *f*, *f* that shuts off the cold air from outdoors by

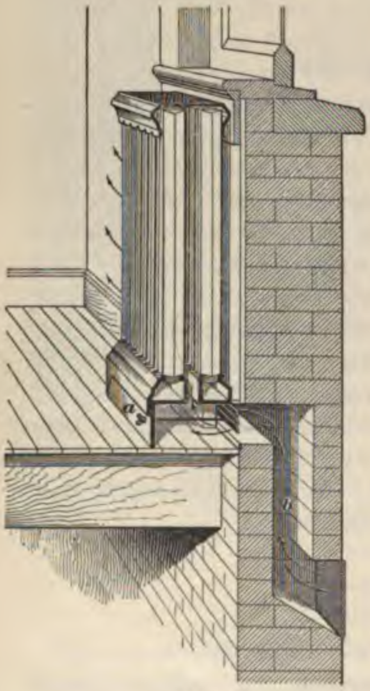


FIG. 19

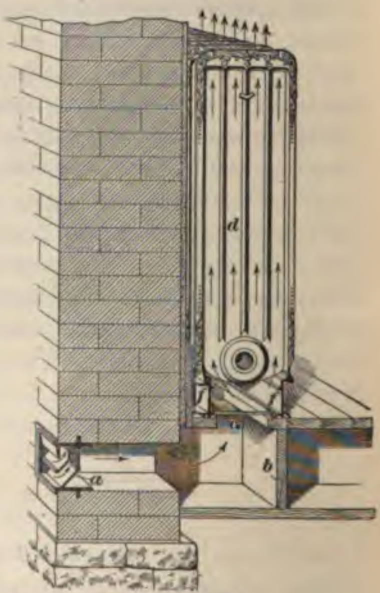


FIG. 20

closing the opening *c*, and with the same motion opens communication with the inside of the room, so that when the outer air is shut off, the air of the room circulates through the flues, and the radiator then operates as a direct-flue radiator. When the flue is open so that fresh air passes through the radiator from the outer atmosphere, the base communication with the room is closed. The front of the base, including the damper, can be easily removed for

cleaning purposes. The damper can be operated by a slight pressure of the foot on the end of a rod that projects through the front of the base.

In places where there is a liability of heavy winds blowing in rain or snow through the wall box, it is advisable to place a galvanized sheet-iron bottom in the cold-air flue, between the floor line and the face of the wall box, so that rain blown in will flow out again without damaging the ceiling underneath.

The method just shown of connecting the cold-air pipe or tube from outside is extensively used in small apartments, churches, and also in office buildings, an outlet vent being provided in each room for the escape of air from the room. The results obtained are usually fairly satisfactory, provided the radiator is large enough to warm the air that will be extracted by the vents. The warm fresh air makes steam-heated rooms far more comfortable than those heated by direct radiation. But, if the radiators are too small, the rooms will not be comfortably warm.

37. Wall Boxes.—Wall boxes made of galvanized sheet iron are too light to support mason work over them and are not durable; therefore, they should be avoided. Strong cast-iron boxes should be used, which can be purchased from radiator manufacturers and are constructed to dimensions conforming to brick measurements. They are generally made 5 inches by $17\frac{1}{2}$ inches. The outside measurement of the lip that is provided for attaching a galvanized sheet-iron connecting sleeve to the radiator is about $4\frac{3}{4}$ inches by 17 inches. This sleeve should be used whenever possible, because it makes an air-tight conduit between the wall box and the radiator for the incoming cold air.

38. Damper Arrangement.—Direct-indirect radiators that are made with separate bases and that have double dampers are better than those that depend simply on a single damper in the cold-air inlet, because with a single-damper arrangement, circulation inside the radiator cannot be obtained when the outside air is shut off, and the radiator

therefore becomes less effective as a heater. Sliding or swinging doors are often fitted to the base of radiators having a single damper to overcome this defect.

A single-damper arrangement is shown in Fig. 21. The damper *a*, which is of the plain slide type, is operated by the rod *b* extended into the room through the base box of

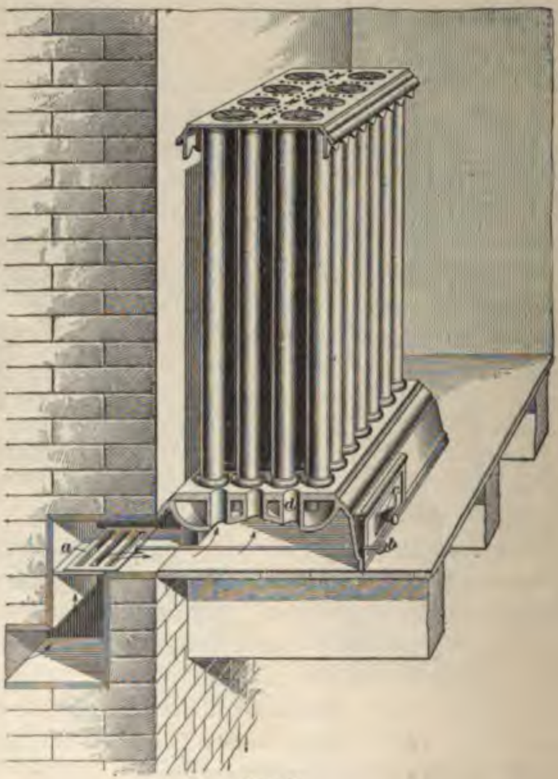


FIG. 21

the radiator. To close the cold-air supply, the rod is pushed in, and if inside circulation is desired, the hinged door *c* may be opened by hand. The radiator shown is of the Nason improved type, having vertical tubes *d* passing through its steam base and supplying air to the spaces between the tubes.

39. A double-damper arrangement is shown in Fig. 22 in connection with a box base that is commonly used for direct-indirect flue radiators. Where the cold-air opening comes in above the floor, the collar *a* is connected by a sheet-metal sleeve to the wall box. The radiator is set over the box base so that the sections fit into the recesses *b*, *b*. The cold-air damper *c* is shown open· the circulating

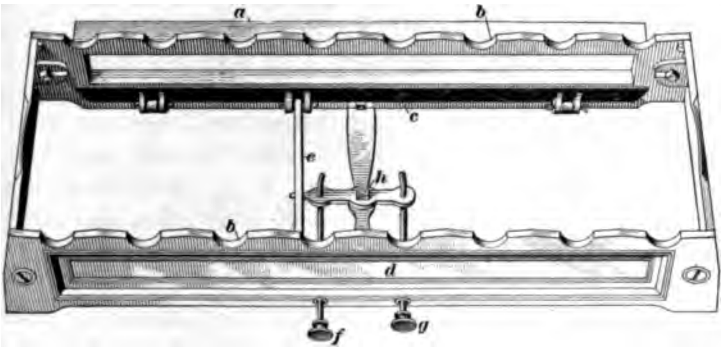


FIG. 22

damper *d* is shown closed. Both dampers are connected by a rod *e* that is operated by rods *f* and *g*, connected with *e* by the lever pivoted at *h*. To close the cold-air damper, and open the circulating damper, the rod *f* is pushed in with the foot. To open the cold-air damper, the rod *g* is pushed in with the foot.

40. Where the cold-air inlet is brought up through the floor under the radiator, the opening in the floor to be covered by the damper in the base is usually made much larger than the opening at the back, where the cold-air inlet is above the floor. The sizes of the openings are usually given by the manufacturers in their catalogues. Ordinarily the width of the floor opening is 4 inches, varying from about 4 inches to 24 inches in length, according to the number of sections in the radiator. The width of the opening above the floor is usually about $2\frac{3}{4}$ inches, the length varying with the number of sections in the radiator.

41. Defects of Installation and Operation.— The defects most commonly met with in the installation and operation of direct-indirect radiators are lack of vent flues to carry the air from the rooms, locating the radiator where it will be exposed excessively to wind, carelessness in operating the radiator valves, and failure to keep up the necessary steam pressure. If properly installed and attended, direct-indirect radiators give very satisfactory results.

42. If vent flues are omitted, or if they are too small to remove the air from the building quickly enough to insure a good draft through the direct-indirect radiators, the latter will warm the air chiefly by direct radiation, and their surface may then prove insufficient to properly heat the building. When the street doors of large office and other tall buildings are opened the upward pressure exerted by the outer atmosphere on the column of warm air in the stairway openings causes a reverse current through the flues of direct-indirect radiators located on the upper floors, the warm air being thereby forced outward from the rooms into the atmosphere through the direct-indirect radiator flues. In other words, the stairway openings act as chimneys, for which the direct-indirect radiator flues on the top floors serve as the upper opening. This is one of the reasons why it is difficult to satisfactorily heat tall buildings by direct-indirect radiation, unless a large vent shaft, having openings to each room, is provided, and a revolving door placed at the entrance of the building.

If the wind blows strongly against one side of a building heated by direct-indirect radiators, the wind will raise the air pressure in the building to a point higher than that at the sheltered side, and the air in the building is thus blown down through the direct-indirect radiator flues and out through the wall boxes on the sheltered side of the building. In such a case, it is necessary to close the fresh-air openings to the radiators on the sheltered side, and check the cold-air openings on the windward side, in order to have satisfactory heating results during the prevalence of strong winds.

If the radiator valves are not intelligently handled during cold weather, the radiator may become partly filled with water of condensation, which may freeze and burst the radiator. This is liable to happen if either the steam valve or the return valve of the radiator is closed. To prevent freezing, it is necessary that steam be permitted to flow through direct-indirect radiators during cold weather, if the fresh-air damper is open. Should the boiler pressure be permitted to go down, the radiator may freeze and burst because the lack of pressure fails to produce a satisfactory circulation of steam in the radiator, which results in an accumulation of water.

INDIRECT RADIATORS

INTRODUCTION

43. Indirect radiators are located outside of the rooms to be warmed by them; consequently, the heat given off by indirect radiators is not emitted by radiation, but is given off by convection only. Air from the outer atmosphere, or an inside supply from the building, flows upwards between the heating surfaces of the indirect radiators, becomes warmed, and enters the room through registers, so that in buildings warmed by indirect radiators, the only visible parts of the heating installation in the rooms that are warmed are the registers. Indirect radiators are usually suspended from the basement or cellar ceiling. A cold-air duct, generally made of galvanized sheet iron, conveys air from the outer atmosphere to the under side of each radiator, and the hot-air pipe connects the upper part of each radiator to the register. The radiators are encased by suitable casings of galvanized sheet iron or wood lined with tin or asbestos, as the circumstances demand.

Indirect radiators are made in a number of forms. Some are entirely made of cast iron, others partly of cast iron

and partly of wrought iron. Cast-iron radiators generally have flutings, fins, or pins to increase the exterior or heating surface as much as possible, also to cause the air to impinge on the heated surfaces as it flows through the radiator. The pins and fins, or flanges, are so placed that the air shall take a zigzag course while passing through the space between the sections.

A number of indirect radiator sections when joined together are called an **indirect stack.**

INDIRECT RADIATOR CONSTRUCTION

44. Prime Surface Indirect Radiators.—A prime surface indirect radiator with flutings that form vertical flues between the sections is shown in Fig. 23. The sections are

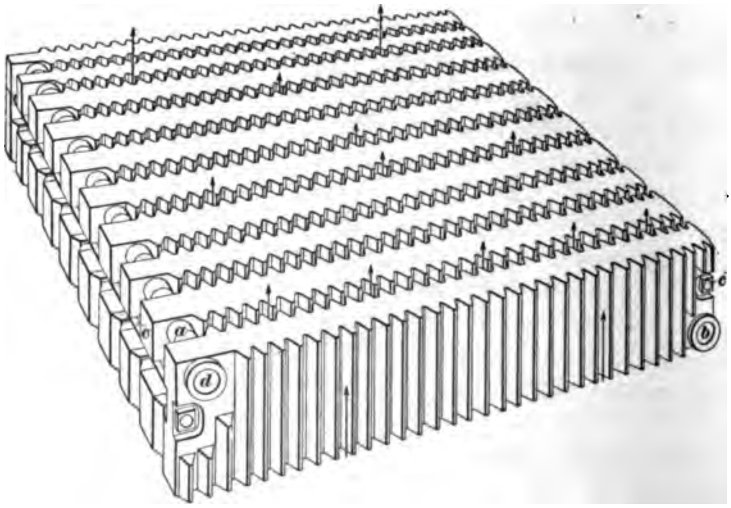


FIG. 23

cast in the form of hollow boxes, and are joined together by slip nipple connections at *a* and *b*, the bolts *c* being used to draw the sections together and make steam-tight joints.

The steam-supply pipe connects to the opening *d*. Steam is delivered to the upper left-hand corner of each section and circulates through each section, the water of condensation being drained off through the return pipe connected to the return tapping at *b*. The air flows upwards between the sections, as shown by the arrows, and enters the rooms to be warmed. The air vent for this indirect radiator may be connected to the return pipe between the return valve and the radiator.

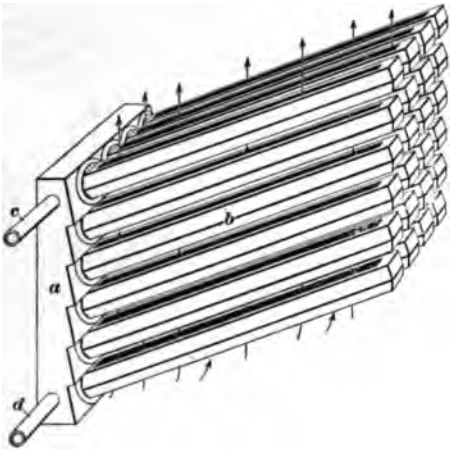


FIG. 24

45. A prime surface radiator composed of a cast-iron box *a* and a number of Bundy loops *b* screwed into it is shown in Fig. 24. The loops are inclined so that they may drain back into the steam box *a*. Steam enters *a* through the supply pipe *c*, and the condensation water is drained away from the bottom by the return pipe *d*. Air passes upwards between the loops, as shown by the arrows, and enters the rooms.

46. A prime surface indirect-loop radiator in common use is shown in Fig. 25. The sections are screwed together with right-and-left nipples, as at *a*. The increased surface is obtained by corrugating the loops. In order to show the corrugations clearly, the left-hand section is partly broken away. Steam circulates from the header through the loops and back to the header again. Air passes upwards between the corrugations and becomes heated before it enters the room. This is a good form of heating surface, particularly

if the upper row of corrugations is arranged over the under row so that the air will have to pass up through the radiator in a zigzag fashion.

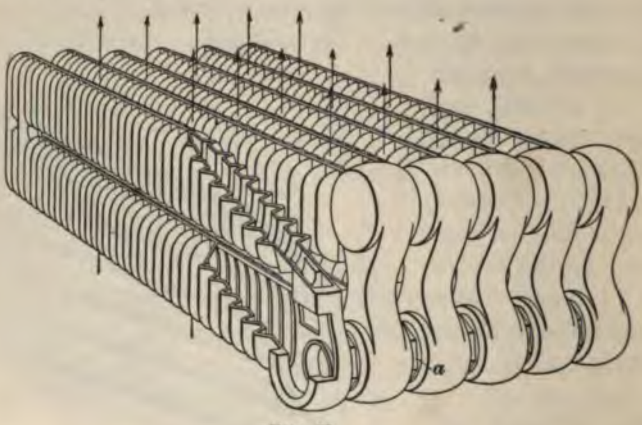


FIG. 25

47. Fig. 26 shows another effective form of indirect radiator. It is composed of a number of wrought-iron Nason tubes *a* screwed into the cast-iron base box *b*, the inclined position of the tubes insuring an effective drainage. The steam enters the base through the upper tapping *c*; the return pipe connects to the tapping *d*. This is a very effective heater, because the tubes are staggered, that is, each tube is located immediately over the space between the two tubes under it, so that the air in passing through the radiator is brought into intimate contact with a very large part of the heating surface of the tubes.

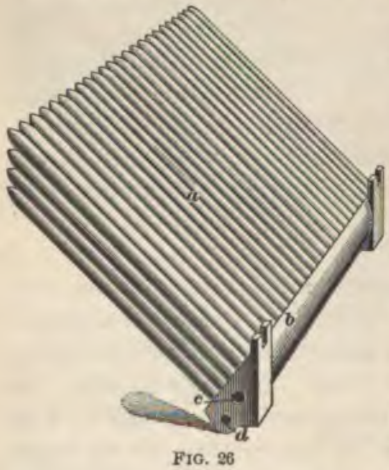


FIG. 26

48. Extended Surface Indirect Radiators.—Fig. 27 illustrates an extended surface indirect stack for steam heating, which is known as the **Excelsior.** A perspective view of a complete stack is shown in Fig. 27 (*a*), while Fig. 27 (*b*) shows a cross-section through three headers. The extended surfaces are composed of fins, or flanges, *a* cast on the loops, as shown. The sections are tapped at one corner of the loop, so that the steam and return connections are in line and at the bottom of the loop. The loops are screwed together with nipples, as at *b*. The illustration shows a steam-supply pipe *c* connected to the right-hand side of the stack, as it should

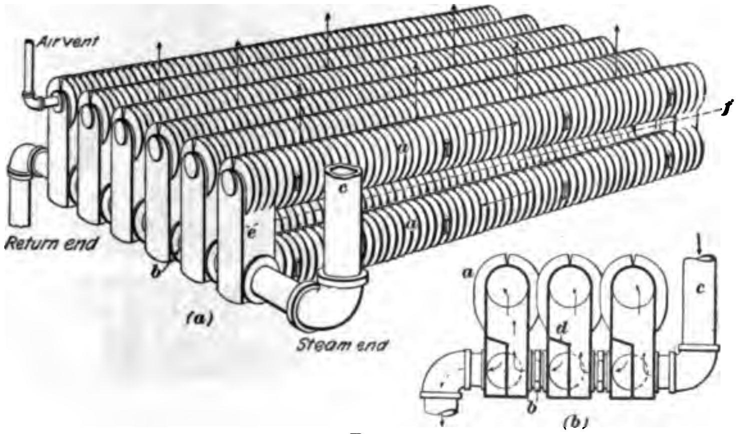


FIG. 27

always be, because each section has a partition *d* that deflects the steam around the sections, as shown by the arrows. This insures a positive circulation throughout the stack. If the steam pipe is connected to the other end of the stack, the circulation will be imperfect and water hammer will result.

In making up this stack, care should be taken to make the distance between sections such that the flanges will interlock about $\frac{1}{8}$ inch. This is found to give the best results if the draft is good. The sections can be connected up with extra long nipples to give additional area between the sections, if

conditions should require the introduction into the room of a large volume of air at a comparatively low temperature, as occurs in warming rooms liable to be well filled with people. It will be noticed that the header end of the stack is deeper than the return end; therefore, if the radiator is correctly hung, that is, with its center line *e f*, Fig. 27 (*a*), perfectly level, the upper and lower tubes will have an inclination that allows the water of condensation to drain from them.

49. A form of indirect radiator having extended surfaces formed by fins, and that is particularly adapted to

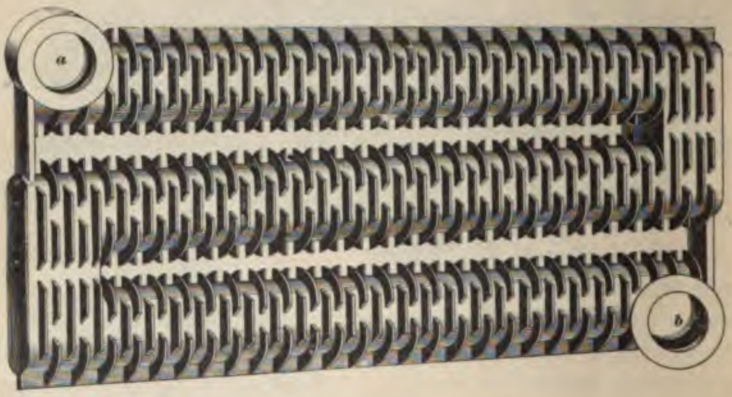


FIG. 28

hot-water heating, is shown in Fig. 28. The sections can be joined by a push nipple or screw nipple. Hot water enters the upper opening *a*, flows slowly through each section, and returns through the return pipe connected at *b* to the boiler. Owing to the fact that the temperature of the hot water in the heating apparatus is lower than that of steam, hot-water indirect radiators require to be larger than steam radiators.

50. In many indirect radiators the heating surfaces are extended by means of pins, whence the name **pin radiators**

is derived. A common form is shown in Fig. 29. The sections are hollow castings with pins extending from the cheeks, as shown. A horizontal partition or division plate runs through each section from the header end to a point near the return end, to compel the steam to travel the full

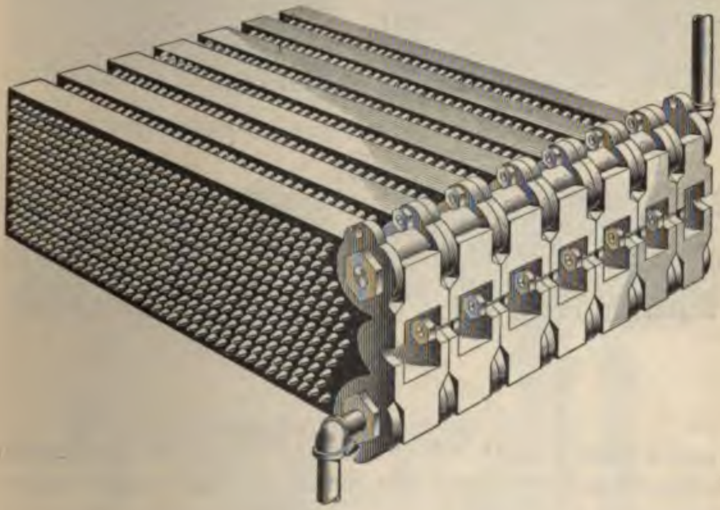
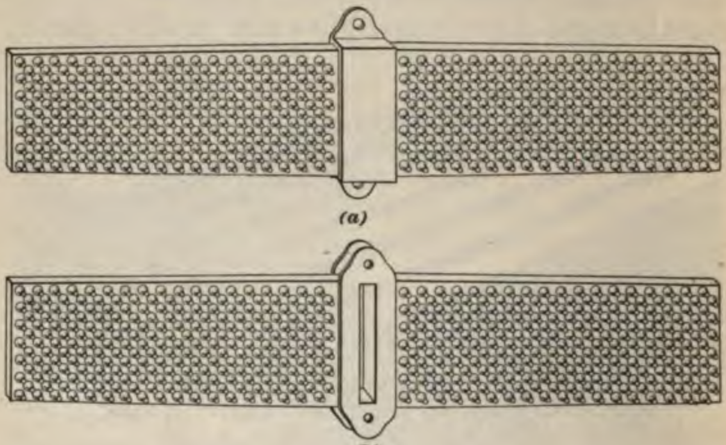


FIG. 29

length of each section before it reaches the return pipe. The sections shown are put together with slip nipples and bolts. Air passes upwards between the pins in a zigzag fashion, and thus becomes warmed before entering the building.

51. Fig. 30 (*a*) shows an end section of an indirect radiator known by the trade name of **Gold pin radiator.** The end section may be used for the steam-inlet end or for the water-outlet end. In the first case it is called the **head-section;** in the second case it is spoken of as the **drain section.** Fig. 30 (*b*) illustrates an intermediate section. Each section has 10 square feet of heating surface. This form of radiator is connected up with short bolts at the top

and bottom of the flanged joints between the sections, a paper gasket being placed between the flanged openings of the sections. The paper used is a heavy quality of plain



(a)

(b)

FIG. 30

manila paper soaked in boiled linseed oil. The head-section is tapped usually at the side or on top for steam connections, and the drain section is tapped at the bottom for return connections.

52. There are many other forms of indirect pin radiators, but in a general way their construction is about the same as that of those illustrated. Among these other forms may be mentioned the **Perfection** and the **school radiator.** The Perfection radiator has a central partition dividing each section into an upper and lower chamber. The supply pipe is connected at the top and the return pipe at the bottom. Right-and-left nipples are used for connecting the sections. The school radiator has large pins and a deeper section than the other radiators described. It is intended to be used with forced-draft systems. It has large air passages and is designed to warm a large volume of air properly. The sections are connected with right-and-left nipples.

53. Tappings of Indirect Radiators.—The supply inlet of indirect radiators is either at the top, the end, or the face of the end section, and the return outlet is either on the face, end, or bottom. Indirect radiators usually have the inlet and outlet tapped for the same size of pipe as direct radiators of the same size. If a different size of tapping is wanted, it must be specially ordered.

INDIRECT RADIATOR INSTALLATION

54. Flues and Casings.—Fig. 31 shows a Bundy angle

FIG. 31

indirect radiator connected up against the outer wall; it

also shows the sheet-metal casings and air ducts. The stack is suspended from the floor joists by hangers *a*, *a* that support the cast-iron steam base, and by rods *b* that support the loops about one-quarter from the end. The lower end of each rod *b* is bent to the form of a hook, a 2-inch or 2½-inch by ½-inch iron bar *c* being placed in the hooks, as shown. These hangers are secured to the floor joists by lag screws, or bolts and nuts. The cold-air duct takes its supply from the outer atmosphere through a perforated screen having a shield over it at *d*. The cold air is injected into the casing *e* at a point where the radiator is farthest from the casing, to give an unobstructed inlet. The hot-air duct is built in the brick wall, as shown at *f*, its lower opening being taken from the widest part of the air space above the radiator stack. An ordinary wall register *g* is located in the side wall of the room to be heated, and is provided with louvre valves. Air flows through the radiator and into the room as shown by the arrows. A sheet *h* of corrugated asbestos is placed on top of the galvanized-iron casing to prevent the joists and floor above the radiator from becoming too warm. Steam enters the radiator at the top of the box casting, and the water of condensation escapes through the pipe *i* connected to the bottom of the same casting. The temperature of the room is regulated by opening or closing the register valves. Incidentally, the ventilation of the room is also affected by operating these valves.

55. A **double casing** for an indirect radiator suspended from floor joists is shown in Fig. 32. The outer casing *a* should be made of crimped galvanized sheet iron. It should clear the radiator about 1 inch all around. An inner casing *b*, which is placed about ½ inch from the radiator, reaches from the lower side of the radiator stack to the top of the outer casing. This closes off communication between the cold-air space *c* and hot-air space *d* except through the radiator, and thus compels the cold air to pass through the radiator; if the space between the casings is insulated with corrugated asbestos, it also prevents the side of the casing from becoming

overheated. To insure a thoroughly cool floor over the radiator, a frame 2 inches by 1 inch is nailed to the joists all around, as at *e*. The space inside this frame is filled with a sheet *f* of corrugated or air-cell asbestos. A sheet of galvanized iron is then nailed to the under side of the wooden frame to form the ceiling of the hot-air space *d*. The hangers and supporting bars are next put in place and the radiator placed in position. The inner casing *b*, made of

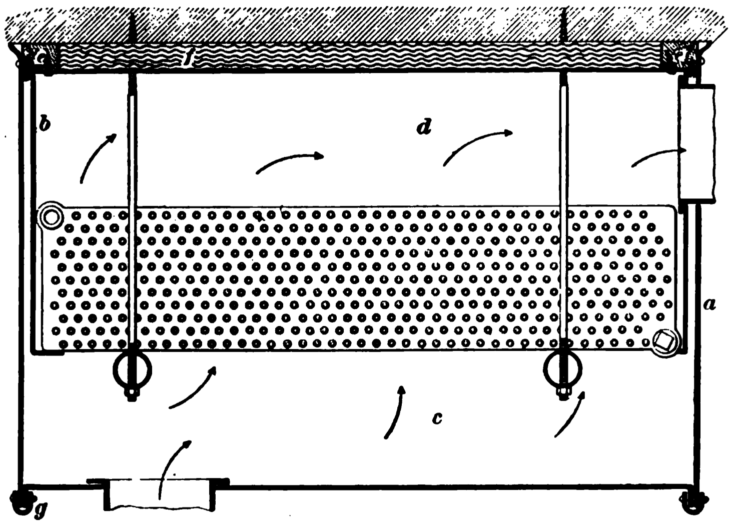


FIG. 32

crimped galvanized sheet iron, is then secured in position by wood screws to the under side of the wooden frame *e*. The outer casing is now put around the radiator, the top being secured to the frame *e*. The pipe connections are next made through the sides of the casing. The bottom piece is then put in place and either double seamed or bolted to the side sheets with a slip joint, as shown at *g*. The hot-air and cold-air connections are finally made to the casing.

The air space above an ordinary indirect stack, forming the hot-air chamber, should be at least 8 inches high. It

should be more if possible, to permit the air passing through the stack to easily reach the outlet pipe.

The cold-air connection under a stack can be somewhat smaller than the hot-air connection, but the space beneath the stack must not be less than 8 inches. These spaces are necessary in order that the air may pass uniformly up through the radiator without undue resistance.

56. **An indirect casing with mixing valve** is shown in Fig. 33. A galvanized sheet-iron pipe *a* connects the cold-air space *b* to the warm-air pipe *c* of the indirect stack.

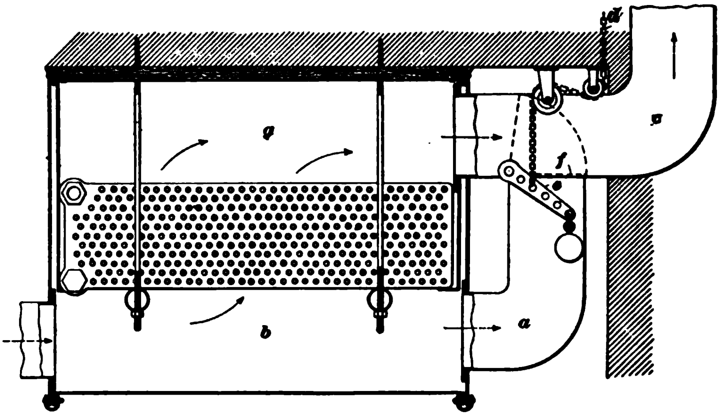


FIG. 33

The chain *d*, terminating in the room to be warmed, connects with the weighted lever *e* of the mixing valve. If the air entering the room from the indirect stack is too warm, the chain is pulled up, and the valve *f* rises so that then a quantity of cold air will flow from *a* to *c* and mix with the warm air that flows from *g* to *c*. By adjusting the chain, the hot and cold air can be regulated so that the temperature of the air flowing into the room can be changed to suit the requirements. This is a very desirable combination, because the temperature can be regulated without changing the volume of air required for satisfactory ventilation.

57. Fig. 34 shows how a trunk cold-air duct *a* that supplies a number of indirect stacks is connected to the side of the casing. The trunk duct is run along the ceiling, and

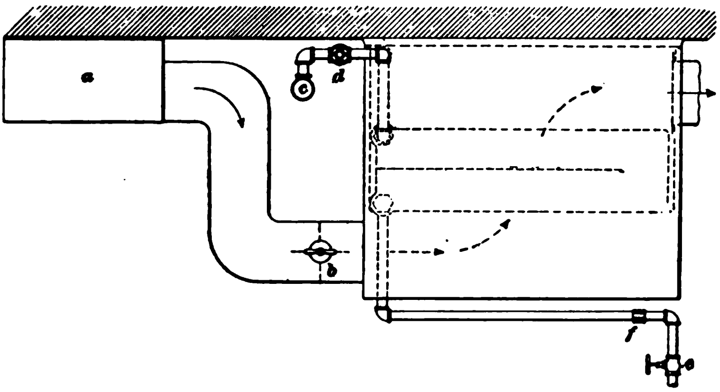


FIG. 34

the branch drops down with an offset, a damper being located at *b*. The steam main is shown at *c*; the steam valve to shut off the stack is located at *d*; the return valve is shown at *e*, and a right-and-left coupling is located at *f* for making final connection.

58. Twin Stacks.—When conditions require the installation of a number of indirect radiators, a marked saving in space and piping can often be effected by grouping them in pairs, which method has the additional advantage of often being more pleasing to the eye than the installation of the same number of radiators singly. A pair of indirect radiators thus grouped together is spoken of as a **twin stack.** Fig. 35 shows a twin-stack installation. One casing surrounds the two radiators, but is divided by a central galvanized sheet-iron partition *a*, into two separate chambers *b* and *c*, one for each radiator. The cold air enters the bottom of each chamber through inlet pipes having dampers *d*, *d*, both inlet pipes communicating with the same cold-air duct *e*. The vertical flues *f*, *f* that conduct the

hot air upstairs are placed on top of the offsets *g*, *g*. The passage of the air is shown by the arrows. The air duct *e*

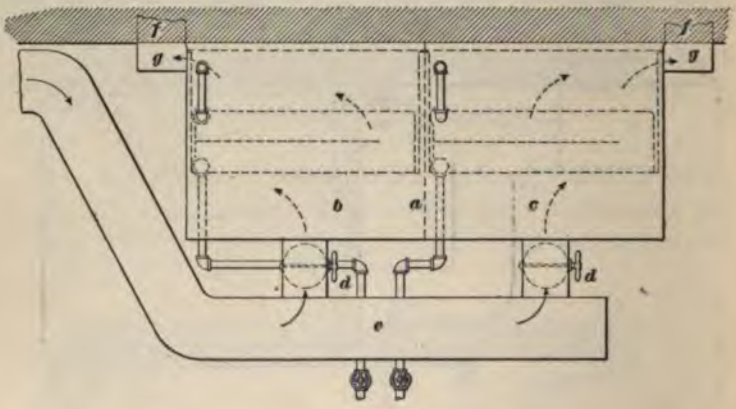


FIG. 35

must have twice the sectional area of the inlet pipe to the chambers *b* and *c*.

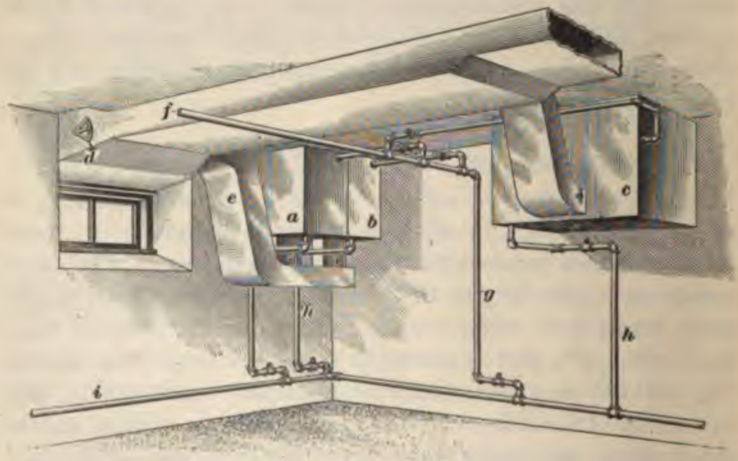


FIG. 36

59. Connection from Window to Stacks.—Fig. 36 shows how stacks *a*, *b*, and *c* may be connected with cold-air

ducts to a window opening. A damper *d* is located in the main duct leading from the window to shut off the cold-air supply to all the radiators. The trunk duct is shown running straight along the ceiling to supply other radiators. A branch *e* supplies the twin radiators *a*, *b*, separate dampers being located in the cold-air supply branches underneath; a separate damper is also placed in the branch to *c*. A steam main *f* runs along under the trunk duct, the steam branch to the stack being taken off the top of the main, as shown. A drip, or bleeder, pipe *g* is located at the end of the main to remove condensation from it. The return pipes *h*, *h*, and also the drip *g*, are each furnished with a check-valve to prevent water in the return main *i* from backing up into them. The hot-air pipes from the stacks are not shown.

In making cold-air duct connections to windows, care should be taken not to obstruct the light in the cellar. If it is necessary, a supply casing should be made with inside windows, the casing acting as a cold-air box.

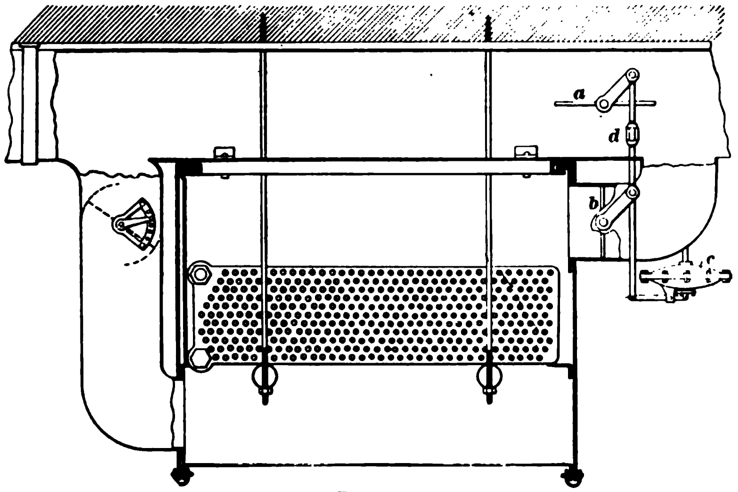


Fig. 37

60. Thermostat Attachments to Indirect Stacks. Fig 37 shows how thermostatic appliances may be arranged

to control balanced dampers *a* and *b* of an indirect stack. The object of the **thermostat** is to so control the air supply as to maintain a uniform temperature in the rooms to be warmed. A diaphragm chamber *c* containing a diaphragm, the whole constituting the thermostat, is connected by a rod to the dampers *a* and *b*. When the temperature of the air in the room warmed by the radiator becomes too high, the pressure on the diaphragm in *c* is increased sufficiently to move the dampers in such a manner that the cold-air damper *a* is opened farther and the hot-air damper *b* is closed a little more. When the temperature becomes too low in the room, the pressure in *c* is reduced and the motion is reversed, so that the resulting temperature of the incoming air is increased by reducing the volume of the cold air and increasing the volume of the hot air at the dampers. A right-and-left adjustment sleeve is located on the rod at *d* so that the dampers may be perfectly adjusted. Indirect stacks provided with automatically controlled dampers that change the temperature without changing the volume of the incoming air, are the best heating devices for warming buildings, and if a fan is used to insure a positive, even flow of air, the results are as nearly perfect as can be obtained in practice.

61. Window Indirect Stacks. — Fig. 38 shows an indirect stack located in a window breast. The cold-air supply may be taken from the floor, as shown at *a*, or through the wall, as with a direct-indirect radiator. Warm air passes up through the radiator and into the room through the register face *b*. All radiators placed in recesses and enclosed by screens or casings should have a proper arrangement for the circulation of the air. The casing of each should be made with an inlet for the cold air as near the floor as possible, and an outlet for the warm air at the top. In some situations an outlet is required at the side; the radiator should then be low in height so that a deflector can be placed over it to deflect the air to the outlet; or, the radiator may be finished with a screen whose

grille work is open the full length and height of the

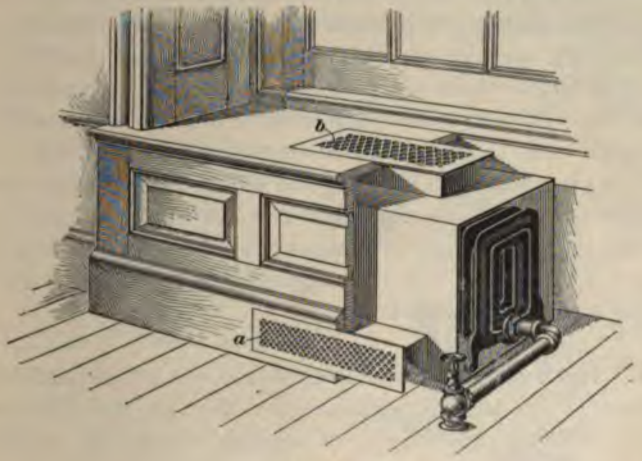


FIG. 38

radiator, the screen being at least 2 inches lower and 4 inches higher than the radiator.

62. Floor Radiators.—Fig. 39 shows a floor radiator. The stack is supported from the joists by suitable iron bars, the radiator casing being made somewhat in the form of a register box. Care must be taken in this class of work to

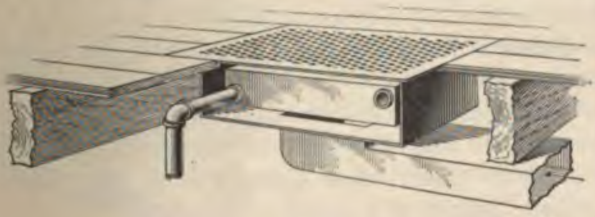


FIG. 39

make proper provision for the air to circulate uniformly through the radiator. Floor radiators are not very desirable because dust and dirt are swept into them.

63. Brick-Set Indirect Stacks.—Indirect stacks are sometimes encased in brickwork instead of sheet iron, but this is more costly and occupies more floor space than sheet-iron casings, and consequently brickwork is not much used, except in cases where large radiators are used in connection with fans. Where such chambers are built, they should be arranged with large cast-iron doors beneath and over the stack to give access to it. A good method of building brick chambers is to have the entire front made of iron and secured so that it can be removed bodily for access to the stack. This will allow the stack to be removed without tearing out the brickwork.

64. Indirect Radiator Registers.—In all natural-draft systems of warming by indirect radiation, the flues and registers should be large. A register should be at least twice the area of the flues, so that the velocity of the air flowing into the rooms may be reduced sufficiently low to prevent perceptible drafts. The registers used for indirect heating should be of a better quality than those used for furnace heating, because the entire work is of a higher character. Each register should be fitted with shutters or valves set in a frame fastened to the face. The frames should be closely fitted and securely attached to the sheet-metal flues, to prevent dust from working out around the frames and soiling the walls. In wooden walls the register should be fastened by screws to the studs, or wooden frames may be placed around the face of the flues. For brick walls it is advisable to build a cast-iron frame into the walls to receive the register. These frames are usually made with a beveled back, so that they may be dovetailed into the wall, which prevents them from being pulled out. They are usually made from 2 to 4 inches in depth.

65. Screens.—Screens can be made from woven wire attached to iron frames fitted into openings in the walls. They are occasionally used instead of registers, but as they require separate dampers, they are not so well adapted for

the purpose as regular registers. Screens or ornamental grille work are very appropriate, however, for radiator enclosures and for openings larger than can be closed by a register.

66. Hangers for Indirect Radiators.—Fig. 40 shows how $\frac{5}{8}$-inch round-iron hangers *a* for indirect radiators can be easily and strongly attached to floor joists or wooden beams, as *b*. One end of the hanger is flattened and is fastened to the side of the beam by two $\frac{7}{16}$-inch lag-screws. The lower end of the hanger is bent over to fit a $2\frac{1}{2}'' \times \frac{1}{2}''$ iron bearing bar *c* that supports the indirect stack *d*. This is an easy hanger to put up after the top sheet *e* and insulation of the casing are put in place.

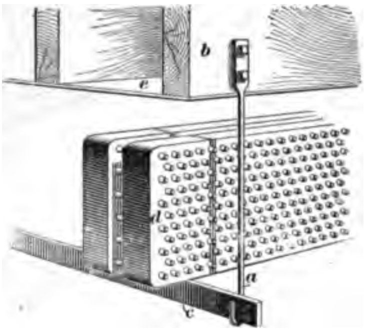


FIG. 40

An **iron-beam hanger** for an indirect stack is shown at *a*, Fig. 41. A piece of $1\frac{1}{4}'' \times \frac{3}{8}''$ bar iron is twisted as shown. One end is bent to form a hook that will receive a $2\frac{1}{2}'' \times \frac{1}{2}''$ bearing bar *b*. The upper end has a hole drilled to receive a bolt that draws the clamps *c*, *c* together over the lower flange of the iron beam. This makes a strong hanger. The radiator casing should enclose the hanger. Therefore, the hangers should be placed close to the radiators, so that the sides of the casing will not be more than 1 inch away from the heating surfaces.

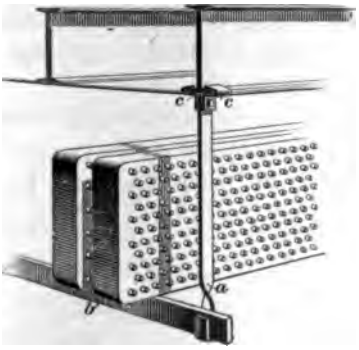


FIG. 41

67. Fig. 42 (*a*) shows a simple arrangement for hanging a radiator with $2\frac{1}{2}'' \times 2\frac{1}{2}''$ angle iron bars and $\frac{5}{8}$-inch rods. One end of the rods is flattened and fastened to the beams or joists by two $\frac{7}{16}$-inch lagscrews; the other end is threaded. The four hangers being in position, the two angle irons are attached and held by nuts. The radiator is then put in place.

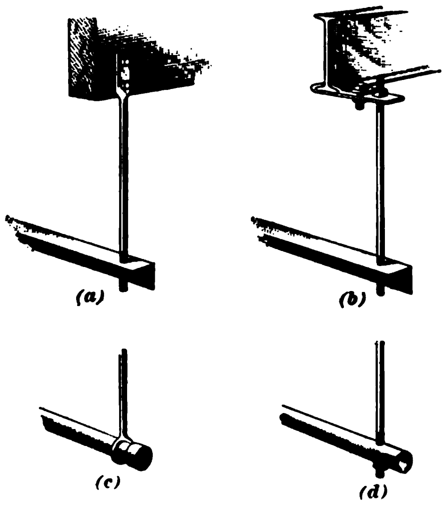


Fig. 42

Fig. 42 (*b*) shows how an arrangement similar to that just shown may be attached to an I beam. To give a wide range of adjustment, the $\frac{5}{8}$-inch rods are threaded at both ends and supplied with nuts. The clamp attached to the beam is made of $2\frac{1}{2}'' \times \frac{3}{8}''$ iron; the angle irons are $2\frac{1}{2}'' \times 2\frac{1}{2}''$.

In Fig. 42 (*c*) a $1\frac{1}{4}$-inch pipe is used for supporting the radiator. The hanger rod has an eye fitting the pipe, whence this particular form is called an **eyebolt.**

Fig. 42 (*d*) shows the pipe support drilled to pass over the threaded hanger rod, which arrangement permits vertical adjustment, which is preferable, as then the stack can readily be leveled or the parts graded properly.

PIPE COILS

PURPOSE AND CONSTRUCTION

INTRODUCTION

68. Pipe coils are made of wrought-iron or steel-pipe and suitable fittings; they are built in various forms to suit different purposes. Some are used for plate warmers; others are employed for warming rooms, when, for direct heating, they are placed on the side walls or on the ceiling; in the form of multiple coils they are used for indirect heating.

Coils generally require to be built to suit existing conditions, and consequently are not kept in stock by manufacturers, but are built to order, or built by the steam-fitter himself, either in his shop or on the job. Coils employed in warming buildings are generally constructed from standard pipes and standard cast-iron fittings; for those intended to be used in connection with ice machines, evaporating pans, feedwater heaters, etc., forged fittings are commonly employed.

WALL COILS

69. Fig. 43 shows a **continuous flat coil.** It is made of straight pipe connected by return bends. The circulation of the fluid through it is direct and certain, and it is regarded as one of the most efficient forms in common use. The wood cleats, or straps, *a* and *b* are attached to the wall, the hook plates being fastened by screws to these cleats and the pipes being supported by the hook plates. Steam flows

into the coil through the supply pipe *c*; the water of condensation returns to the boiler through the return pipe *d*. Great care must be taken to so attach the hook plates that the pipes will be level, since otherwise pockets for water will be formed in the coils that will produce water hammer. It is not advisable to make continuous flat coils with parallel

FIG. 43

pipes much longer than 15 feet, because of the liability of a settlement in the building that will throw the pipes off the level. The hook plates should be located not more than 5 feet apart to prevent sagging of the pipes, when 1-inch pipe is used for this form of coil, which is sometimes given the name of **trombone coil.**

70. The **pitch coil** is similar to that shown in Fig. 43, except that the pipes are all laid with a pitch down from the steam inlet on top to the return connection at the bottom. The return bends are tapped to give the pitch. This form of coil is not as neat as the trombone coil, but it drains better and is a more efficient heater. In making up pitch coils, right-hand threads can be used throughout, but in making short trombone coils it is necessary to use right-and-left threads on the pipes, because the fittings cannot be revolved. Long trombone coils, however, can be made with right-hand threads throughout, because the pipes will spring enough to allow of revolving the fittings.

71. The **return coil** is shown in Fig. 44. It is composed of two manifolds *a* and *b* that are connected by a number of pipes, as shown. Steam enters the top of the upper manifold and flows through the coil, the water of condensation being extracted from the lower end of the manifold *b*. If the coil is short, say 12 feet or less, it

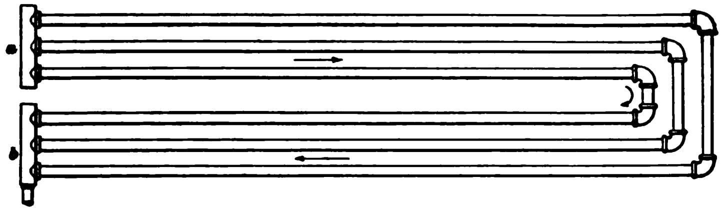


FIG. 44

may be connected up with the pipes level. If it is long, however, it is advisable to spring the manifolds apart a little to give a sufficient pitch in the direction of the arrows, so that the pipes will drain freely. In making up these coils, the long horizontal pipes are first screwed into their respective headers, and then right-and-left connections are made between the elbows. For use with exhaust steam, return coils with manifolds are superior to continuous coils, since they offer less resistance to the flow of steam through the coil.

72. The **angle coil** shown in Fig. 45 is used where one coil is placed on two adjacent sides of a room. Unequal

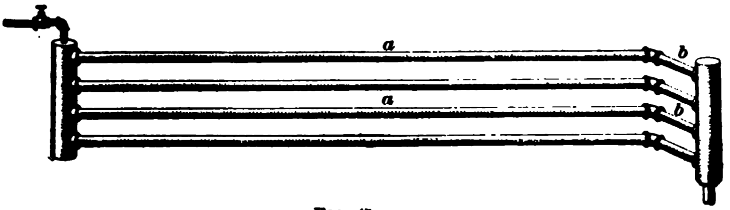


FIG. 45

expansion of the long pipes *a*, *a* is taken care of by the pipes *b*, *b*, which serve as spring pieces, and vice versa. In

making up this coil, the pipes, located over one another, are parallel. The pipes *b*, *b* are connected last with right-and-left threads, the elbows being right and left.

73. In the **miter coil** shown in Fig. 46 the pipes are connected to two manifolds *a* and *b*. The circulation is likely to be uneven, because the fluid entering at *g* will naturally, owing to its momentum, flow to the end of the manifold, and so a greater quantity will enter the pipe *e* than the pipe *f*. The path through *e c* is shorter than that through *f d*, and the friction being less, the main part of the current

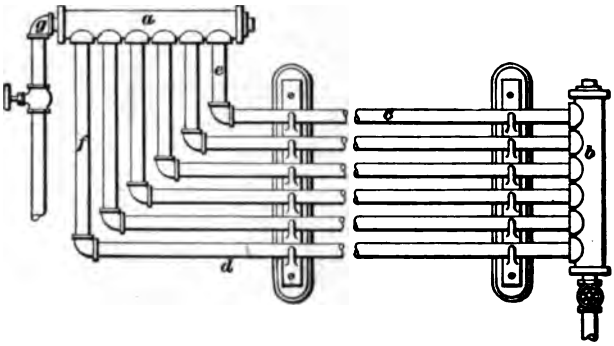


FIG. 46

will go that way. The horizontal pipes being connected to the manifold *a*, the vertical pipes will permit the several long pipes to expand independently as their varying temperatures may require. The vertical pipes will bend or yield sufficiently to accommodate the difference in expansion. Miter coils are commonly used when continuous coils cannot be employed.

74. If a coil is made by connecting two manifolds, as in Fig. 47, it will be difficult to keep the coils steam-tight. The upper pipes will expand more than the lower ones, and will either bulge or spring as shown, or will crack themselves, or break some of the connections, or something must yield

when the pipes expand unequally. The miter and angle coils overcome this difficulty.

FIG. 47

75. A **double miter coil** is one in which two miter coils are joined together at their return ends by one double-branch manifold, one return pipe being used for both miter coils. These coils, however, are seldom used.

SPECIAL AND BOX COILS

76. Spiral coils, cylindrical coils, and coils made in other special forms are used extensively for water heaters, etc. They are made, according to order, by pipe-bending experts employed by pipe establishments. The worm-coil is a cylindrical coil of this class.

77. When several flat coils are massed together as

FIG. 48

shown in Fig. 48, the device is called a **box coil.** Steam enters the upper manifold and flows through each of the

pipes down to the lower manifold, where the water of condensation is drained away by the return pipe. The box coil shown is built up with pitched pipes. Formerly coils of this character commonly served as indirect radiators, but lately they have been superseded largely by indirect radiators of cast-iron.

HOT CLOSET

78. Fig. 49 shows a **hot closet** located in a butler's pantry. The closet is warmed by a double-return manifold

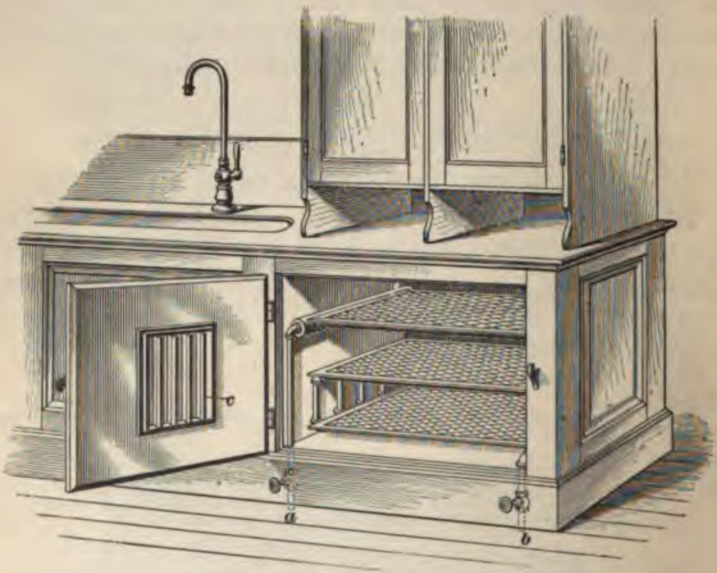


FIG. 49

coil. The pipes forming the coils are so arranged as to give three shelves. A woven-wire screen is laid on each row of pipes on which the plates, etc. are placed. The coil is supplied by steam through the valve *a*, whose wheel handle projects into the pantry. The condensation escapes from the coil through the return valve *b*, whose wheel handle also

projects into the pantry. The closet is lined with galvanized sheet iron, a layer of corrugated asbestos being placed between the sheet-iron casing and the woodwork. The door is lined inside with sheet iron and asbestos, and has a register *c* placed in the center of the panel. The coils are usually made with from four to six rows of pipe, according to the size of the hot closet desired. The coil is supported at the ends by flat pieces of iron plate or an iron frame made of band or angle iron. In constructing hot closets, care must be taken to insulate them properly, to prevent overheating the woodwork around them.

RADIATION CALCULATIONS

HEAT LOSSES FROM BUILDINGS

ESTIMATING HEAT LOSSES

79. Heat escapes from buildings in two ways: first, by conduction through the windows, walls, floor, and roof, and, second, by ventilation or leakage of warm air. The loss from the latter cause will depend on the tightness of the windows and doors and on the thoroughness of the construction of the walls, especially in wooden buildings. If the outer walls are exposed to the wind, the loss of heat by conduction will be increased from 10 to 30 per cent., while the loss by escape of air if they are not wind-tight, will be increased to an unknown amount.

The rate at which heat will be lost through walls and windows has been found, by careful experiment, to be proportional to the difference in temperature between the inside and outside air. The rate of loss under ordinary conditions, in British thermal units, and in rooms that have only a moderate exposure to wind, is shown in a diagram by Alfred R. Wolff, M.E., given in Fig. 50. The heat losses under various conditions may be read directly from the diagram,

the line *a* showing loss through vault light; *b*, single window; *c*, single skylight; *d*, 4-inch brick wall; *e*, double window; *f*, double skylight; *g*, 8-inch brick wall; *h*, 1-inch pine board door; *i*, 12-inch brick wall; *j*, concrete floor on earth; *k*, fireproof partition; *l*, 2-inch pine board, heavy

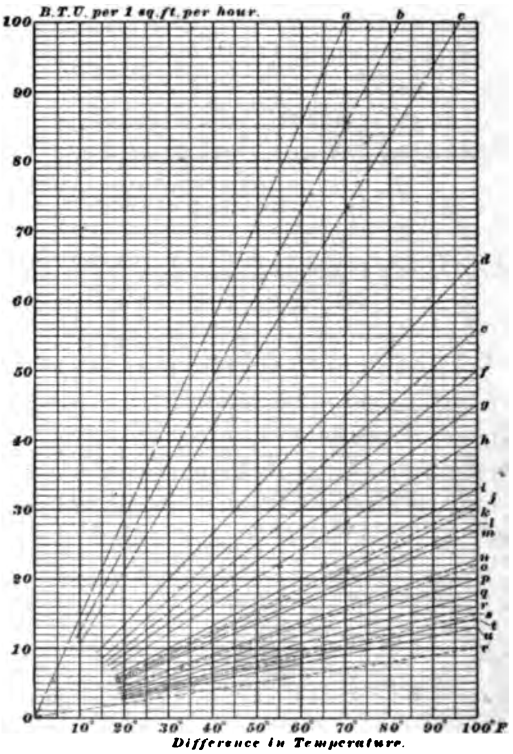


FIG. 50

door; *m*, 16-inch brick wall; *n*, 20-inch brick wall; *o*, concrete floor on brick arch; *p*, 24-inch brick wall; *q*, 28-inch brick wall; *r*, 32-inch brick wall; *s*, wood floor on brick arch; *t*, 36-inch brick wall; *u*, 40-inch brick wall; *v*, double wood floor.

The rate of heat loss through the lathed and plastered walls of frame buildings of ordinary American construction,

which is not given in Wolff's diagram, varies between .18 and .25 British thermal unit per square foot of surface per hour per degree of temperature difference, the variation being accounted for by differences in the quality of the workmanship and material, and in the general character of construction. When in doubt, it is good practice to use the highest coefficient here given.

The requisite allowance for different exposures is indicated by the figures on the diagram given in Fig. 51, which shows that for north and west exposures 25 per cent. should normally be added to the calculated heat loss, while for east and south exposures an allowance of 15 and 5 per cent., respectively, should be made. A further allowance of 10 per cent. is made for heating the air that constantly leaks in through cracks and crevices, and a similar allowance is advised for the loss of heat through floors and ceilings. When the rooms are comparatively small, the results given by the use of the diagram in Fig. 50 are increased by the percentage indicated by the figures given inside the circles on the diagram in Fig. 51.

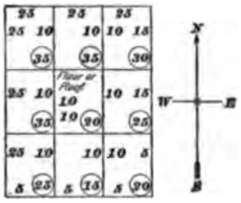


FIG. 51

If brick walls are made double, with an intervening air space, the loss of heat is less than that of a solid wall having an equal thickness of brick. The saving will be about .07 or .08 British thermal unit per square foot.

The heat losses will be increased by circumstances approximately as follows:

Where the exposure is northerly, and the winds are strong, 35 per cent.

When the building is heated during the day, and is allowed to cool off partially during the night, the exposure being moderate, 10 per cent.

Same, northerly exposure with high winds, 40 per cent.

When buildings, such as churches and audience rooms, are heated occasionally, for a day only, and are cold for intervals of several days, 50 per cent.

The temperature of cellars that are not warmed may be assumed for purposes of calculation to be 32°. Vestibules and corridors, frequently opened to the outer air and not heated, may be assumed to have a temperature of 20°.

HEAT-LOSS COMPENSATION

80. In many instances, the loss of heat from the room will be partially compensated for by the heat emitted from gas lights, electric lamps, etc., and by the heat given off from the persons occupying the room. The amount of heat given off per hour from these sources is about as follows:

	British Thermal Units
Each adult person	400
Ordinary 5-foot gas burner, 15 candlepower	4,800
Welsbach incandescent lamp, 50 candlepower	2,000
Electric incandescent lamp, 16 candlepower	220

In lecture halls and large audience rooms, the amount of heat given off by the audience and the lights may equal or exceed that which is lost through the walls and windows. When this occurs, it becomes necessary to lower the temperature of the fresh-air supply below the desired temperature of the room during the presence of the audience. Thus, the actual amount of heat required may vary from hour to hour, although the atmospheric temperature is stationary.

PROPORTIONING RADIATION

EMISSIVE CAPACITY OF RADIATORS

81. The following general conclusions are deduced from the results of extensive experiments and tests of radiators:

The various materials used for radiators do not show any considerable difference in emissive capacity under similar conditions of internal and external temperature.

The rate of emission is practically the same for hot water or steam, for equal differences in temperature.

The rate of emission is not affected by the internal volume of the radiator tubes, provided that the sectional area is large enough to afford good internal circulation.

In still air, radiators having but one row of tubes are more effective than those having two or more rows.

TABLE II

HEAT EMISSION FROM VERTICAL-TUBE RADIATORS

Difference in Temperature Degrees F.	Massed Tubes		Single Row of Tubes	
	40 Inches High	24 Inches High	40 Inches High	12 Inches High
50	1.29	1.54	1.46	2.01
60	1.33	1.58	1.50	2.06
70	1.36	1.62	1.54	2.12
80	1.39	1.66	1.58	2.17
90	1.41	1.70	1.62	2.22
100	1.46	1.74	1.65	2.27
110	1.49	1.78	1.69	2.32
120	1.52	1.82	1.73	2.38
130	1.56	1.86	1.77	2.43
140	1.59	1.90	1.81	2.48
150	1.63	1.94	1.85	2.53
160	1.66	1.98	1.88	2.59
170	1.69	2.02	1.92	2.64
180	1.73	2.06	1.96	2.70
190	1.76	2.10	2.00	2.75
200	1.80	2.14	2.03	2.80
210	1.83	2.18	2.07	2.85
220	1.86	2.22	2.11	2.90
230	1.90	2.27	2.15	2.96
240	1.93	2.31	2.19	3.01
250	1.97	2.35	2.23	3.06

TABLE III

HEAT EMISSION FROM COMMERCIAL RADIATORS

Name or Kind of Radiator	Dimensions: Number of Sections	Dimensions: Rows of Tubes	Dimensions: Radiating Surface Square Feet	Dimensions: Height Inches	Tests of Kelsey and Jackson: Temperature Difference Degrees F.	Tests of Kelsey and Jackson: Coefficient of Emission	Tests of Woodward and Campbell: Temperature Difference Degrees F.	Tests of Woodward and Campbell: Coefficient of Emission	Tests c Dunn a Mack: Temperature Difference Degrees F.
Wrought-iron, vertical pipes	12	4	53.60	36.0	94.0	1.620			
Wrought-iron vertical pipes,									
Nason	16	3	47.94	36.0	90.0	1.669	145.0	1.700	
					146.6	1.830	144.0	1.690	
							133.0	1.620	
Wrought-iron, hot-water,									
Western No 2	12	4	41.19	32.5					133.2
									130.1
									137.6
Wrought-iron, steam, West-									
ern No. 2	12	4	43.33	32.5					144.8
									148.2
									158.5
Steel, hot-water, Western No. 1	12	4	45.13	35.0					146.2
									147.6
									159.5
Steel, steam, Western No 1	18	4	47.24	35.0					144.6
									143.0
									155.0
Cast-iron, Bundy	16	1	45.11	37.0					153.2
									154.4
Cast-iron, Bundy	10	3	79.00	37.0	149.0	1.640			159.4
Cast-iron, Bundy Elite	9	2	41.80	36.0					153.1
									157.1
									171.1
Cast-iron, Reed	13	1	48.70				151.0	1.688	
							147.0	1.627	
							136.0	1.523	
Cast-iron, Royal Union	11	3	49.12	37.0	151.0	2.080	151.0	1.688	150.0
							139.0	1.565	137.5
							130.0	1.582	157.0
Cast-iron, Royal Union	26	3	52.81	17.0					153.0
									152.0
									159.0
Cast-iron, steam, Perfection	13	1	49.90		91.0	1.630	147.8	1.456	
							147.0	1.374	
							144.0	1.433	
Cast-iron, steam, Perfection	12	1	48.17	37.3					147.0
									156.3
									166.5
Cast-iron, steam, Perfection	10	2	40.20	37.8					151.5
									145.4
									165.6
Cast-iron, hot-water, Perfec-									
tion	12	1	48.00	37.0	89.0	1.664			
					150.0	1.550			
Cast-iron, steam, Ideal	10	1	40.00	38.0					155.3
									158.7
									155.1
Cast-iron, hot-water, Ideal	10	1	40.00	38.0	140.0	1.610			154.5
									167.6
									158.4
Cast-iron, steam, National	10	1	40.00	38.0					154.0
									153.0
Cast-iron, extended surface,									160.0
Whittier	3	1	38.65	30.0	142.0	1.130			152.6
									164.3
Cast-iron, indirect, Michigan		1	38.20		91.0	1.434			151.0
					140.0	1.270			

With equal surfaces, in still air, low radiators are more effective than tall ones, and horizontal tubes are more effective than vertical ones.

82. The total emission of heat per hour, from direct vertical-tube radiators, in still air per square foot of external surface, for each degree difference of temperature, is given, in British thermal units, in Table II.

83. Prof. Rolla C. Carpenter, in the "Transactions of the American Society of Heating and Ventilating Engineers," has made public the results of tests on a large number of radiators in the market; an abstract of these tests is given in tabular form in Table III. The coefficient of emission is the number of British thermal units emitted per square foot per hour per degree of temperature difference.

84. The comparative efficiency of flue radiators and plain-surface radiators having the same size is indicated by the experimentally derived values given in Table IV. The

TABLE IV

COMPARISON OF FLUE RADIATORS AND PLAIN RADIATORS

Temperature Difference Degrees F.	Radiating Surface Square Feet		B. T. U. Emitted per Hour per Square Foot per Degree		Total B. T. U. Emitted per Hour per Degree		Number of Test
	Extended	Plain	Extended	Plain	Extended	Plain	
173	57.80		1.65		95.37		1
172		40.40		1.97		79.58	1
158	6.40		2.05		13.12		2
154		4.24		2.39		10.13	2
153	63.10		1.39		87.81		3
153		41.20		1.85		76.22	3
155	7.18		1.90		13.64		4
159		4.50		2.24		10.08	4

data in the second, fourth, and sixth columns refer to the radiators in their original condition, that is, having the usual ribs shown in Fig. 7; the data in the third, fifth, and seventh columns refer to the same radiators with their ribs removed.

The table gives the result of tests made on four different radiators by Messrs. Denton and Jacobus in July, 1894.

It will be observed that while the rate of emission from the plain surfaces is higher than that from the extended surfaces, the total emission is less; this result is due to the great difference in area of the actual emitting surfaces.

85. The average rate of emission of heat from ordinary indirect radiators that are enclosed in a box and deliver warm air to rooms above through a vertical flue is shown in the following tables:

TABLE V

HEAT EMISSION FROM EXTENDED-SURFACE INDIRECT RADIATORS

Height of Flue Feet	Velocity of Air Feet per Second	Emission of Heat per Sq. Ft. per Hour, per Degree Difference B. T. U.
5	2.90	1.70
10	4.10	2.00
15	5.00	2.22
20	5.70	2.38
25	6.30	2.52
30	6.70	2.60
35	7.14	2.67
40	7.50	2.72
45	7.90	2.76
50	8.20	2.80

The radiators to which Table V refers are the ordinary cast-iron extended-surface indirect radiators; those to which

TABLE VI

HEAT EMISSION FROM PLAIN-SURFACE INDIRECT RADIATORS

Velocity of Air Feet per Second	Heat Emitted B. T. U.	Velocity of Air Feet per Second	Heat Emitted B. T. U.
3	3.42	12	6.93
4	4.00	14	7.50
5	4.50	16	8.06
6	4.94	18	8.50
7	5.33	20	9.00
8	5.71	22	9.42
10	6.33	24	9.79

Table VI refers are made of 1-inch pipe, massed closely together, with air circulated over their surfaces by mechanical means.

RULES FOR RADIATOR SURFACE

86. General Rules.—The method of computing the amount of radiator surface required for any given service is as follows:

Having ascertained the amount of heat to be supplied, in British thermal units per hour, the difference in temperature between the air to be heated and the heating medium used in the radiators is found. If hot water is used, the temperature considered should be the average of its temperatures at entering and leaving the radiator. The coefficient of emission may then be found by referring to the preceding tables. The coefficient or number that corresponds most nearly to the given difference of temperature and to the kind of radiator to be used should be multiplied by the difference in temperature, in degrees. The product will be the total emission of heat per square foot per hour that may be expected.

The area of radiator surface required may then be found by dividing the total amount of heat required per hour by the emission from 1 square foot as computed.

For heating by direct radiation, the amount of heat to be supplied per hour, neglecting leakage, will be equal to the heat losses per hour through the windows and walls.

Heating systems in the United States of America are generally so proportioned that the amount of radiating surface provided will be sufficient to meet the requirements of zero weather, and ordinarily the difference between the temperature of the radiating surface and that of the air in the room is 150°, under which conditions it is customary to figure that each square foot of radiating surface emits 2 British thermal units per degree difference of temperature, or a total emission of 300 British thermal units per hour.

EXAMPLE.—A certain building requires a supply of heat amounting to 200,000 heat units per hour, and it is to be heated by direct radiation supplied with steam having a temperature of 220°. The radiators are to be of the Bundy type, 37 inches high. How many square feet of radiating surface will be required to maintain the temperature of the air in the building at 70°?

SOLUTION.—The difference in temperature between the heating agent and the air will be 220° − 70° = 150°. The coefficient of emission, by Table III, is 2.02. Then the area of radiating surface required will be $\frac{200,000}{150 \times 2.02} = 660$ sq. ft. Ans.

87. A greater amount of heat than is necessary with direct heating is required for indirect heating, on account of the large amount of heat lost by ventilation with the latter system. Of course, no fresh hot air can be introduced unless an equal amount of air be expelled from the room at the same time. Consequently, all the heat contained in the fresh-air current below 70° (or the desired temperature of the room) will be lost by passing off with the spent air—that is, by ventilation. The fresh-air current must be heated from 20° to 50° hotter than the desired temperature of the room, so that, in cooling to that

temperature, it will give off an amount of heat sufficient to make good the loss by conduction through the walls, windows, etc. Thus, in using a current of fresh air having a temperature of 110°, to maintain a room at 70°, the external temperature being zero, $\frac{70}{110}$ of the heat imparted to the current will be lost by ventilation, and only $\frac{40}{110}$ will be available to compensate for the loss of heat from the room through the windows and walls.

With indirect heating, to find the total heat loss for any case arising in practice, multiply the heat loss through the windows and walls by the difference between the temperature of the heated fresh-air current and the external temperature; divide this product by the remainder obtained by subtracting from the difference between the temperature of the heated fresh-air current and the external temperature the difference between the temperature at which the room is to be maintained and the external temperature.

In contracts for heating, it is customary to specify that the building must be heated to 70° F. with the external air at zero; taking these values the directions just given will assume a simpler form, as follows:

Rule.—*To find the total heat loss with an indirect heating system, multiply the heat loss through the windows and walls by the temperature of the heated fresh-air current; divide this product by the difference between the temperature of the heated fresh-air current and 70.*

Or,
$$L_t = \frac{L\,T}{T - 70}$$

where L_t = total heat loss;
L = heat loss through windows and walls;
T = temperature of heated fresh-air current.

EXAMPLE.—The heat loss through windows and walls being 90,000 British thermal units per hour, and the temperature of the hot fresh-air current 120°, what is the total heat loss?

SOLUTION.—Applying the formula just given,

$$L_t = \frac{90{,}000 \times 120}{120 - 70} = 216{,}000 \text{ B. T. U.} \quad \text{Ans.}$$

88. The radiating surface required with an indirect heating system is computed in the same manner as described in Art. **86**, except that the total loss of heat is first computed from the heat loss through windows and walls by the rule in Art. **87**.

EXAMPLE.—The loss of heat from a certain building, by conduction through the walls and windows, is 200,000 British thermal units per hour. It is desired to heat the building by the indirect system with natural draft, with steam having a temperature of 220°. The average temperature of the hot air at entering the rooms should be 40° above that in the rooms. The building is two stories high, and all the radiators are to be located in the basement. How many square feet of radiator surface will be required to maintain the internal temperature of the building (neglecting the basement and attic) at a temperature of 70°, the outer air being at zero?

SOLUTION.—The total heat loss, by the formula in Art. **87**, is $\frac{200{,}000 \times (70 + 40)}{(70 + 40) - 70} = 550{,}000$ B. T. U. The height of the flues will be about 10 ft. on the first story and 20 to 25 ft. to the second story. By Table V, the coefficients of emission for these heights are 2 and 2.52 B. T. U., respectively, the average being $\frac{2 + 2.52}{2} = 2.26$. The difference between the temperatures of the steam and the cold outer air is 220°. Then, $\frac{550{,}000}{2.26 \times 220} = 1{,}106$ sq. ft. Ans.

A method for determining approximately the amount of indirect radiating surface required is to add 60 per cent. to the direct radiation that would be necessary to do the heating without ventilation; or, in other words, to multiply the direct radiation by 1.6.

89. For direct-indirect, or semidirect, heating, the area of radiator surface required may be found by computing the area for direct heating, and adding 25 per cent., that is, multiplying by 1.25.

90. Baldwin's Rule for Direct Radiation.—One of the most simple, and probably most correct, empirical rules used in computing the size of direct radiators is that originated by Mr. Wm. J. Baldwin and is as follows: "Divide

the difference between the temperature at which the room is to be kept and that of the coldest outside atmosphere by the difference between the temperature of the steam pipes and that at which you wish to keep the room, and the quotient will be the square feet, or fraction thereof, of plate or pipe surface to each square foot of glass, or its equivalent in wall surface."

From this the following rule is obtained:

Rule.—*To find the minimum number of square feet of direct radiation required, multiply the difference between the desired temperature of the room and that of the external air by the sum of the glass surface and equivalent glass surface, in square feet. Divide the product by the difference between the temperature of the heating surface and that of the air in the room. The temperatures are to be taken in degrees Fahrenheit.*

Or,

$$S = \frac{(T - t)\,G}{t_1 - T}$$

where S = radiation, in square feet;
T = desired temperature of the room;
t = temperature of external air;
G = sum of glass surface and equivalent glass surface;
t_1 = temperature of radiating surface.

The quantity of heating surface found by this simple rule merely compensates for the amount of heat lost by transmission through the windows, walls, and other cooling surfaces; it does not provide for cold air entering the room through loosely fitting doors, windows, etc., and an ample allowance must be made for this. Some buildings are so poorly constructed that 50 per cent. or more must be added to the amount of heating surface obtained by the above rule, in order to counteract the cooling effect of these air leakages. A common practice is to add 25 per cent. for buildings of ordinarily good construction. Besides this addition for air leakage, an ample allowance—say 20 per cent.—should be made for rooms exposed to cold winds,

and this allowance should, if possible, be made in the form of an auxiliary radiator to prevent overheating the rooms during moderate weather.

In the application of the above rule, the equivalent glass surface, abbreviated E. G. S., is obtained by dividing the exposed wall surface by 10.

91. The manner of using the rule given in the preceding article can be shown best by an example.

Suppose that there are three rooms *A*, *B*, and *C*, as shown in Fig. 52, of precisely the same dimensions, and, conse-

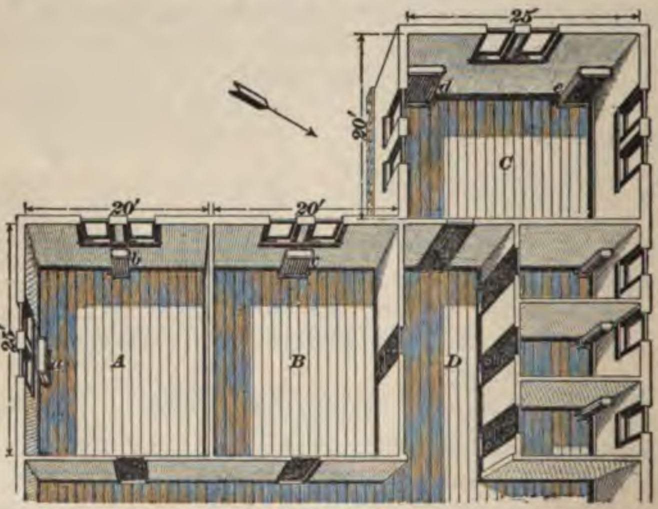


FIG 52

quently, having the same cubical contents, the rooms being each 25 feet long by 20 feet wide, with a 10-foot ceiling. Also suppose that the halls, or corridors, *D* and the other rooms in the building will be warmed to a temperature equal to that desired in *A*, *B*, and *C* by radiators not shown. The amount of heating surface is to be sufficient to maintain a temperature of 70° F. in *A*, *B*, and *C*, assuming that the radiators will be heated by steam having a gauge pressure of 5 pounds, the outside temperature being 10° below

zero. Suppose that the windows are each 6 feet by 3 feet, and that the exposed walls are built of good ordinary brick, lathed and plastered inside.

The amount of glass surface in room A is $6 \times 3 \times 4 = 72$ square feet. The exposed wall surface reduced to equivalent glass surface is $\frac{(25 \times 10 + 20 \times 10) - 72}{10} = 37.8$ square feet. Assuming that in this case the inner walls, ceilings, and floors are not cooling surfaces, the sum of the glass surface and equivalent glass surface for room A is $72 + 37.8 = 109.8$ square feet. The temperature of steam at 5 pounds gauge pressure is 227°, nearly. Substituting in the formula given in Art. **90**, $S = \frac{[70 - (-10)] \times 109.8}{227 - 70} = 56$ square feet, nearly. It will be plain that the difference between 70° above zero and 10° below zero, expressed by $[70 - (-10)]$, is $70 + 10 = 80°$. The number of square feet of radiation so far calculated is sufficient to counteract the cooling effect of the walls and windows; for air leakage, 25 per cent. may be safely added, giving $56 \times 1.25 = 70$ square feet. For exposure to winds, 20 per cent. may be added, giving $70 \times 1.2 = 84$ square feet of direct radiation required. For convenience, this may be divided so as to give two radiators; for instance, the radiator a may be given an area of 56 square feet, and the radiator b an area of 28 square feet. This will so divide the radiator surface that one-third, or 28 square feet, may be used for duty during mild weather; two-thirds, or 56 square feet, for moderate cold weather; and the whole, or 84 square feet, for use during severe weather.

In like manner and under the same conditions, it is found that the sizes of the radiators c, d, and e should be, respectively, 40, 82, and 42 square feet.

If the coldest winds blow in the direction of the arrow, the radiator having 82 square feet should be placed in the left-hand exposed corner of the room C. A better distribution of the radiator surface in this room would be to make d 42 square feet only, and place a radiator having

40 square feet between the windows toward which the arrow points; this will give a more uniform temperature to the room.

It will be observed that *A*, *B*, and *C*, which are three rooms having the same shape and cubical contents, respectively require 84 square feet, 40 square feet, and 124 square feet of heating surface, in order to maintain a temperature of 70° F. in each while the outer atmosphere is 10° below zero.

92. Common Approximate Rule.—A rule known to steam fitters and heating contractors as the *Two-Twenty-Two Hundred Rule* (2–20–200) is a simple, quickly applied rule in quite common use for obtaining the approximate size of a direct-steam radiator. The rule is intended to give an amount of radiation sufficient to comply with the usual specification that the rooms must be heated to 70° during zero weather.

Rule.—*Divide the glass surface, in square feet, by 2, the exposed wall surface, in square feet, by 20, and the contents of the room, in cubic feet, by 200; the sum of the quotients is the amount of heating surface required, in square feet.*

Or,
$$S = \frac{A}{2} + \frac{B}{20} + \frac{C}{200}$$

where S = radiation, in square feet;
A = glass surface, in square feet;
B = exposed wall surface, in square feet;
C = cubic contents, in cubic feet.

EXAMPLE 1.—How many square feet of common cast-iron standard steam radiation is required to heat a room having 180 square feet of glass surface, 900 square feet of exposed wall surface, and 20,000 cubic feet of space?

SOLUTION.—Applying the formula corresponding to the rule,
$$S = \frac{180}{2} + \frac{900}{20} + \frac{20,000}{200} = 235 \text{ sq. ft. Ans.}$$

EXAMPLE 2.—How many square feet of direct steam radiation is required to heat the rooms *A*, *B*, and *C* in Fig. 52?

SOLUTION.—The room A has $6 \times 3 \times 4 = 72$ sq. ft. of glass surface, $(25 \times 10 + 20 \times 10) - 72 = 378$ sq. ft. of exposed wall surface, and $25 \times 20 \times 10 = 5{,}000$ cu. ft. capacity. Applying the formula corresponding to the rule,

$$S = \frac{72}{2} + \frac{378}{20} + \frac{5{,}000}{200} = 79.9 \text{ sq. ft.} \quad \text{Ans.}$$

The room B has $6 \times 3 \times 2 = 36$ sq ft. of glass surface, $20 \times 10 - 36 = 164$ sq. ft. of exposed wall surface, and $25 \times 20 \times 10 = 5{,}000$ cu. ft. capacity. Applying the formula corresponding to the rule,

$$S = \frac{36}{2} + \frac{164}{20} + \frac{5{,}000}{200} = 51.2 \text{ sq. ft.} \quad \text{Ans.}$$

The room C has $6 \times 3 \times 6 = 108$ sq. ft. of glass surface, $(20 \times 10 + 25 \times 10 + 20 \times 10) - 108 = 542$ sq. ft. of exposed wall surface, and $25 \times 20 \times 10 = 5{,}000$ cu. ft. capacity. Applying the formula corresponding to the rule,

$$S = \frac{108}{2} + \frac{542}{20} + \frac{5{,}000}{200} = 106.1 \text{ sq. ft.} \quad \text{Ans.}$$

93. Example 2 of Art. **92** gives an opportunity of comparing the rule given in that article with Baldwin's rule given in Art. **90.** The comparison shows that the results are about the same for ordinary rooms with ordinary exposures. For inside protected rooms the 2–20–200 rule gives results from 10 to 20 per cent. too large, and for very much exposed rooms from 10 to 20 per cent. too small. This shows that good judgment must be exercised in using the 2–20–200 rule, making proper allowance for extreme exposures, and proper deductions for protected rooms.

94. Rules for Semidirect and Indirect Natural-Draft Radiators.—Both Baldwin's and the 2–20–200 rule are for direct radiation. For semidirect radiators, the radiating surface should be 25 per cent. larger, and for indirect natural-draft radiators it should be at least 50 per cent. larger than is given by the rules mentioned. That is, for semidirect radiators, multiply by 1.25, and for indirect natural-draft radiators, multiply by 1.5.

EXAMPLE.—By Baldwin's rule, a certain room requires 75 square feet of direct radiation. (*a*) If the radiation is semidirect, how many

square feet will be required? (*b*) If the radiation is of the indirect natural-draft type, what should its extent be?

SOLUTION.— (*a*) $75 \times 1.25 = 93.75$ sq. ft. Ans.
(*b*) $75 \times 1.5 = 112.5$ sq. ft. Ans.

EXAMPLES FOR PRACTICE

1. A certain room requires a supply of heat amounting to 80,000 British thermal units per hour. How many square feet of direct steam radiation will be required to keep the room at 70° F., the heat transmitted per square foot of radiation per hour being 2 British thermal units per degree difference of temperature, and the temperature of the steam being 220° F.? Ans. 267 sq. ft., nearly

2. How many square feet of direct radiation are required, by the 2-20-200 rule, to heat a room 15 feet by 20 feet, with a 10-foot ceiling and two exposed sides, having three windows $2\frac{1}{2}$ feet by 6 feet, to 70° F. during zero weather? Ans. 53 sq. ft., nearly

3. If the room in example 2 was to be heated by semidirect radiation, what amount of radiating surface would be required? Ans. 66 sq. ft., nearly

4. In a building warmed by indirect radiation, the heat loss through windows and walls is 1,000,000 British thermal units per hour. The temperature of the building being 70° F., and that of the incoming hot air 110° F., what is the total heat loss per hour? Ans. 2,750,000 B. T. U.

5. A room of ordinarily good construction in a frame building has 40 square feet of glass surface and 340 square feet of exposed wall surface. The temperature of the steam is 220° F., of the outside air, 0° F. and the room is to be kept at 70° F. Making an allowance of 20 per cent. for construction, 20 per cent. for exposure, and using Baldwin's rule, how much direct radiation is needed? Ans. 50 sq. ft., nearly

HEATING AND POWER BOILERS

HEATING BOILERS

INTRODUCTION

DEFINITIONS

1. The process of making steam consists in transforming water from the liquid to the gaseous condition. This can be accomplished only by the application of heat. In practice, the steam is made within a closed vessel whose outer surface is brought in contact with direct rays of heat and the hot gases from some burning fuel, the vessel being known as a **steam generator,** or more commonly as a **steam boiler.** For the sake of brevity the qualifying word *steam* is often dropped, and the vessel is then called simply a **boiler.** The surfaces of the boiler with which the water is in contact on one side and the fire or hot gases of combustion on the other side, are called the **heating surfaces**; such surfaces as are in contact with steam on one side and fire or the hot gases of combustion on the other side are known as **super-heating surfaces.** The fuel, which generally is coal, is burned in a suitably enclosed space known as the **fire-pot, firebox,** or **furnace,** and rests on iron bars forming the **grate.** A **draft** by which air is supplied to the burning fuel is created by the chimney or smokestack, which also carries off the waste gases of combustion.

In order to generate steam rapidly and efficiently, it is necessary that the heating surfaces of boilers be arranged

to give a good circulation of the contained water. By **circulation** is meant the setting up of a current in the water that will pass over the heating surfaces in a strong uninterrupted flow as long as heat is applied.

CLASSIFICATION

2. Boilers may be classified broadly as *heating boilers* and *power boilers*. **Heating boilers**, as a general rule, are designed simply for low-pressure heating and carry a steam pressure of not over 10 pounds per square inch. **Power boilers**, as implied by the name, are chiefly used to furnish steam for power purposes, and are divided by some into *medium-pressure boilers*, which carry pressures not above 100 pounds per square inch, and *high-pressure boilers*, which carry pressures in excess of 100 pounds per square inch.

3. Low-pressure heating boilers are commonly made of cast iron. In the construction of fire-tube and drop water-tube types of heating boilers, however, wrought iron and steel are also used.

Medium-pressure power boilers are chiefly made of wrought-iron or steel plates with wrought-iron or steel tubes, and in some forms of tubes with cast or forged fittings. High-pressure stationary boilers are generally composed of steel tubes fitted into wrought-steel connections and have steam drums of steel plates.

SECTIONAL HEATING BOILERS

GENERAL DESIGN

4. Low-pressure steam-heating boilers must be made of a material that will transmit heat readily, and the parts must be so arranged as to absorb the greatest possible amount of heat from the hot gases passing over them. It is also important that the parts be so arranged that they can easily be kept clean and in good condition for the transmission of heat. Such boilers must be so designed as to insure safety,

not only under the stresses incidental to ordinary work, but also when neglected and partly worn out by long service.

Partly for manufacturing reasons, and partly because facility in handling and shipping, as well as ease of repairing, are thereby secured, cast-iron boilers are built up of sections placed either vertically or horizontally. The sections are united in different ways: some manufacturers use threaded nipples screwed into the sections and drums or manifolds; others use tapered nipples and through bolts. A *through bolt* is a long bolt passing clear through the pieces to be held together, and is supplied with a nut and generally with a washer at its threaded end, a washer being often used under the bolt head.

5. The term **sectional boilers** is applied principally to a class of low-pressure cast-iron heating boilers composed of a number of independent sections connected in such a manner that the group will operate as one structure. There are, however, a few forms of water-tube power boilers to which the term sectional boilers may be correctly applied. The sectional construction permits a boiler to be made large or small in capacity by varying the number of sections.

6. The common types of sectional cast-iron boilers differ very little from one another in general outline, the principal difference in construction being found in the form of the sections and methods of connecting them, the disposition of the heating surfaces, and the arrangement of the flues through which the gases of combustion pass to the chimney.

The majority of the boilers specially designed for low-pressure steam heating are built up of vertical and horizontal cast-iron sections in the form of hollow slabs, which rest on a cast-iron base containing the grate bars, the sections being bound together by connections with the steam and water headers at the top and sides of the vertical types of sectional boiler, or by means of bolts passing through lugs cast on the section or through the openings of slip nipples in the water leg and steam space of the sections.

JOINTS

7. Because of their general similarity in form and constructive details, sectional heating boilers may be grouped or classified according to the character of the connections or joints between the sections. These joints may be classified under four heads: (1) *packed joints*, in which a gasket or some form of packing is used, the packing adjusting itself to inequalities in the metal surfaces; (2) *screw joints*, where a thread is cut in opposite sections, which are then joined by means of screw nipples; (3) *slip-nipple joints*, where the joining surfaces are machined to certain forms and connections made by bushings known as *push* or *slip nipples;* (4) *rust joints*, where the joining surfaces are rusted together.

8. A **gasket joint** is shown in Fig. 1. Intermediate, or inner sections, as *a*, and an end section *b* are held tightly together by bolts *c*, *c* passing through flanges or lugs. Gaskets *d*, *d* of asbestos or other suitable material are placed between the faced surfaces of the sections, making a water-tight joint when the joints are drawn up tight. The recess formed at *e* serves to hold the gaskets in place while the sections are being put together.

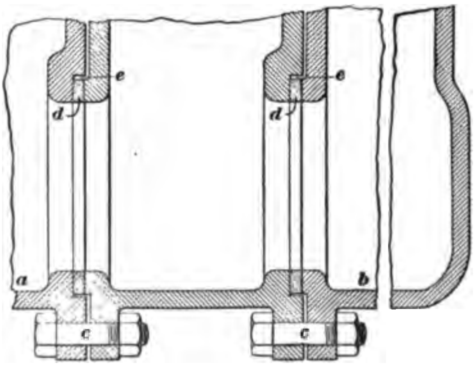


FIG. 1

In some boilers the gasket joints are made in a corrugated form. The faces of the sections against which the gasket is pressed are corrugated, so that the raised parts of one face press the gasket into the recessed parts of the opposite face. This makes a good joint.

9. A **screw joint** between two sections is shown in Fig. 2. An intermediate section *a* is joined to an end

section *b* by means of a right-and-left malleable-iron nipple with a hexagon center to which the wrench is applied in screwing up the nipple. This makes a very secure job, provided that both threaded parts are screwed in tight.

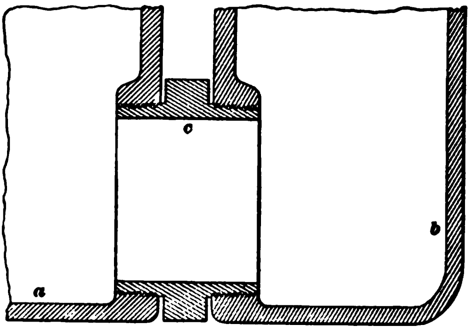


FIG. 2

10. A **push-nipple joint,** also called a **slip-nipple joint,** between two boiler sections is shown in Fig. 3. The inner surfaces of the cast-iron collars *a, a* around the holes are reamed out to a smooth finish and tapered. The push nipple *b* is finished smooth outside and tapered to fit the taper of the holes. The nipples are simply pushed into their respective openings and the sections are drawn together with a long bolt *c* passing through the inside of the heater, or are secured with bolts and lugs, as shown in Fig. 1. The bolt *c* where it passes through the end sections is made watertight by asbestos or other packing wrapped around at *d* and squeezed tight by the nut *e* when it is screwed up. In making up push-nipple joints, great care must be taken to wipe the tapered surfaces perfectly clean and to paint them with graphite before putting the parts together; otherwise, sand or grit may lodge between the surfaces and keep them far enough apart to cause a leak. The graphite prevents the

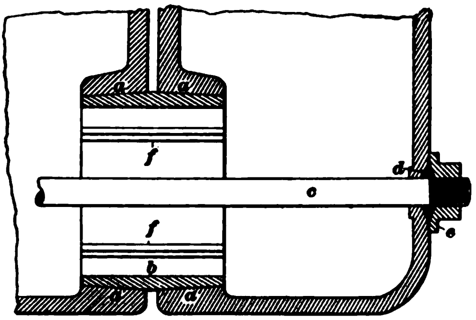


FIG. 3

nipples rusting fast to their seats. Lugs *f*, *f* are cast inside the nipples to hold them while being turned outside, and also to aid in placing or moving them.

11. Long-screw nipple connections are made between the cast-iron boiler sections and outside headers for steam and water. Some manufacturers use special forms of long-screw connections, such, for example, as that shown in Fig. 4. A recess, or socket, *a* is formed in the steam drum or header to receive the packing *b*. The coupling *c* acts as a gland to compress the packing into the socket. In making up these joints, the couplings are screwed over the long screws until they reach the end of the thread at *d*. The end *e* of each long screw is next screwed into the steam drum until *e* projects as many threads inside the drum as the other end will screw into the section *f*. Then all the nipples are screwed up tightly into the sections *f*, when *e* will be run back about flush with the inside of the drum or header, as shown. Asbestos wick or other suitable packing is wound around the long screw and pushed into the socket *a*; the coupling is now screwed tightly down on the packing *b*. The part of the nipple on which the lock-nut is placed has a thread of uniform diameter; the thread of the part screwed into *f* is tapering and thus makes a water-tight joint when screwed home.

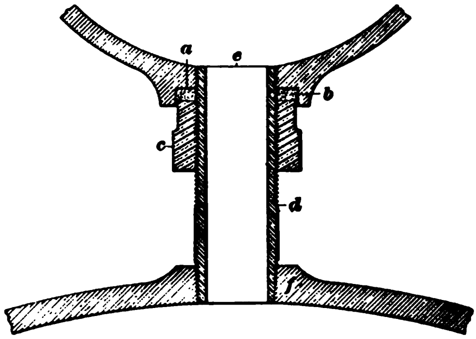


FIG. 4

12. Repairing nipple connections between boiler sections and headers is a matter that frequently taxes the ingenuity. Neither the sections nor the header can be conveniently moved to allow the insertion of a new nipple, and it is therefore customary to make the new connection with one

shoulder nipple and one long-screw nipple, as shown in Fig. 5. The long-screw nipple *a* may be run either into the header *b* or into the section *c*, depending on which has the better face for the gasket joint. The illustration shows the gasket joint made against the section. After the old nipple has been cut out and the parts removed, the long-screw nipple *a* is screwed in as far as it will go. The shoulder nipple *d* and coupling *e* are then screwed in place, and *a* is backed out and screwed tightly into *e*. The packing *f* is next wrapped around the long-screw nipple and the locknut *g* is screwed up tight.

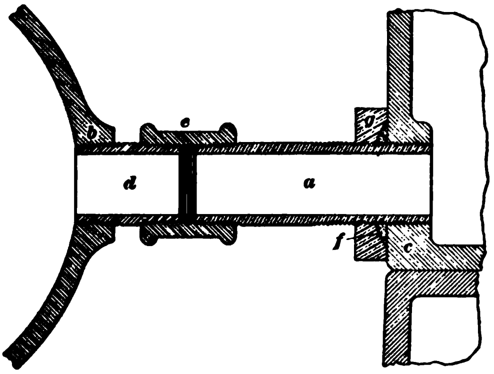


FIG. 5

13. The packed joint deteriorates more or less rapidly, whether inside or outside the boiler, because any irregularity in the adjustment of the parts, due to the presence of dirt, the springing of the castings, or carelessness on the part of the fitter, may leave one portion of the joint loose while the other is drawn up tightly.

The screw joint has the disadvantage of being difficult to separate in case the cracking of one of the sections necessitates repairs, the screw nipple becoming rusted or burned so solidly into the sections that much labor is necessary to get them apart; also, perfect sections are sometimes broken in the separating process. The screw joint is also less desirable as a means of connecting the sections because

of the increased amount of labor necessary in assembling the sections.

The slip joint, made by using push nipples that taper at both ends and are machined to fit closely in correspondingly tapered openings in opposite sections, has the advantage of being easily separated when repairs are necessary. The contact surfaces of the joint are protected from rusting by being coated with graphite, and when the sections are forcibly drawn together by bolts, an absolutely tight rustless joint is secured. The graphite does not deteriorate with age, and its protective lubricating qualities cannot be destroyed by the acids or alkalies sometimes found in the water. The contact surfaces naturally assume their relative positions as the joint is tightened up; when the sections are taken apart for repairs or for increasing the capacity of the boiler by the addition of new sections, the surfaces of the joints are left in good condition and the old nipples can be replaced.

14. A **rust joint** is formed between the sections of heating boilers by placing a putty inducing a rusting of the iron between the surfaces to be joined. One kind of putty is made of iron filings and sal ammoniac, with which a small amount of red lead is sometimes mixed. Another rust-joint filling is made by mixing 10 parts of iron filings with 3 parts of chloride of lime and enough water to form a paste. The rust-joint type of boiler has been largely superseded by the push-nipple types, which can be constructed at less cost and in safer forms.

VERTICAL-SECTION HEATING BOILERS

15. Introduction.—The following description of various types of boilers serves to indicate some of the different constructions at present on the market, and hence will be of assistance in making an intelligent selection of such a boiler as will best suit the requirements to be met, bearing in mind that the capacity of all types is limited by the area of the grate and the disposition of the heat-absorbing surfaces over the fire and in the flues. Catalog ratings are not always reliable, as the peculiar conditions under which every

boiler is to be operated cannot be taken into consideration by the manufacturers, and hence such allowances as may be necessary to satisfy governing conditions must be made in order to meet all the requirements imposed by the character of the work that the boiler is intended to perform.

The makes of boilers illustrated here have been selected from those in the market as showing most prominently the

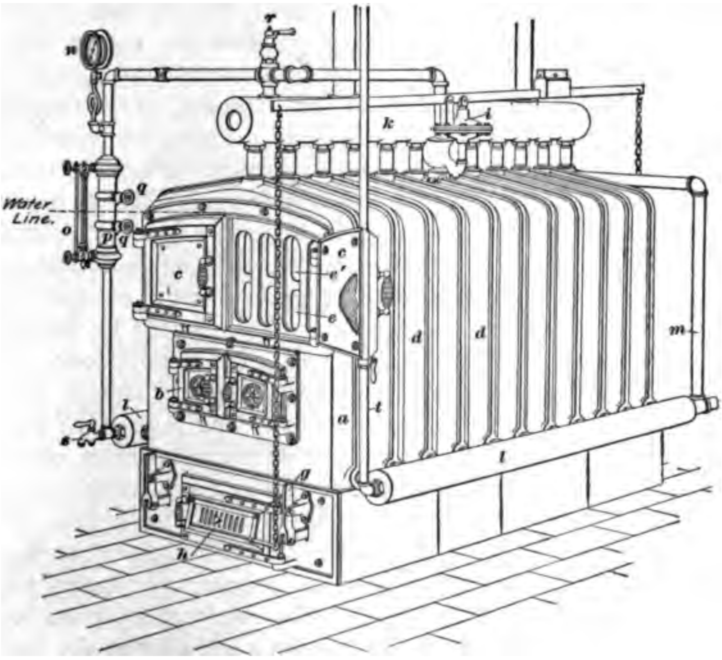


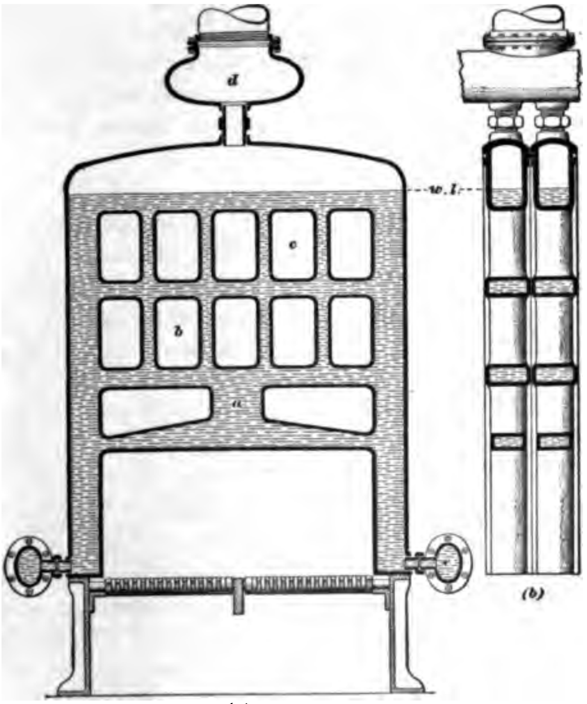
Fig. 6

characteristic features of the different types; the fact of their being described here does not indicate any superiority, nor does the absence of other makes of boilers indicate in any way an inferiority to those here given.

16. Mercer Boiler.—A typical boiler with vertical slab sections and screw-nipple connections, known as the Mercer boiler, is shown in Fig. 6. The vertical cast-iron slab sections are connected into horizontal steam and water drums by screw nipples and long threads. The front slab or

section *a* is fitted with a fire-door *b* and flue-cleaning door *c*, provided with cast-iron linings to prevent the hot gases from burning out the doors. The intermediate sections *d*, *d* have flue spaces *e* and *e'* through which the gases pass, the front sections being shaped to form the firebox. The rear section is shaped so as to divert the gases through the lower flues *e* in the intermediate sections toward the front section, where they are again diverted into the upper row of flues *e'* and return to the rear, whence they pass to the smoke pipe that leads them to the chimney. Clean-out doors, which also serve as check-draft doors or dampers, are arranged at the rear of the boiler, at each side of the smoke-pipe collar, for cleaning the flues. Where the sections come together, a groove is provided, a body of asbestos and red lead being placed therein to make a gas-tight joint. The sections stand on a cast-iron base, which, like the sections, can be extended. The base is fitted with a shaking grate bar for each of the intermediate sections. The grates are operated by levers, as *g*, the ashes being removed through the ash-pit door *h* in which a damper door, operated by the regulator *i*, is provided to admit the air for combustion. The regulator *i* also operates the rear clean-out damper doors, not shown, opening them and closing off the draft through *h* when the pressure rises above the point at which the regulator is set. At the top and lower sides, the sections have openings, tapped with right-hand threads, into which long-screw nipples are screwed. These nipples connect the sections to drums for the steam and water, the steam drum *k* being at the top, while the water or return drums *l*, *l* are at the side. Since the steam space in the boiler proper is comparatively small, the steam drum acts as a reservoir, into which water is sometimes carried with the steam; this water is drained off by a drip, bleeder, or circulation pipe *m* connected with the steam and water drums, as shown at the rear of Fig. 6. In the top of the steam drum are arranged as many outlets as may be required for connecting the pipes that supply steam to the radiating surfaces, similar outlets being provided for connecting the return pipes from the radiators into

the water drums. The boiler is fitted with the usual trimmings, consisting of the steam gauge *n*, water gauge *o* fitted to the water column *p*, to which are also fitted the gauge cocks *q*, *q*, the water column in turn being connected to the steam and water spaces of the boiler, as shown; the safety



(a)

FIG. 7

valve *r* is connected to the steam drum. The draw-off *s* and feed-connections *t* for emptying or filling the boiler are made to the water drums. After the boiler is erected and tested, it is usually covered with some form of asbestos covering to prevent loss of heat.

17. American Boiler.—The American boiler section, shown in elevation in Fig. 7 (*a*) and in cross-section in Fig. 7 (*b*), has a number of tubes *a*, along which the gases

pass freely in their transit to the flues. This construction provides a large amount of heating surface in direct contact with the hottest part of the fire, thereby increasing the efficiency of the boiler. The hot gases pass up between the tubes *a*, thence to the rear-end section, and then forwards to the front through the passages *b*, returning to the smoke flue through the upper passages *c*. The dotted line *w l* shows the water-line of the boiler. The steam mains for warming the building connect to the steam drum *d*, and the water of condensation from the heating system enters both of the return drums, as *e*.

18. Royal Boiler.—The Royal boiler sections, which have elliptically shaped tubular heating surfaces, as shown in Fig. 8, are connected with one another by means of water drums or manifolds at the sides of the boiler and by a steam drum above the sections, the drums being attached to the sections by means of long-screw nipples and locknuts. Each section has an independent free vertical circulation, and forms a portion of the firebox and ash-pit, which are thus completely surrounded by water, the water leg of each section extending to the floor. When the size of the boiler is increased by the addition of sections, the capacity of the boiler is increased by enlarging the grate area as well as the heating surface, each section carrying its own interchangeable triangular-shaped rocking grate bar. The hot gases circulate around hollow cone-shaped projections *a*, *a*, through which the water that rises from the water leg of the section into the waterway *b*, *b* directly over the fire passes into the large waterway *c*, *c*, the steam bubbles being freed at the water-line *A B*. The spaces *d*, *d* between these projections do not form flues, as would seem to be the case on referring to Fig. 8 (*b*), but serve merely to permit the heated gases to circulate around the tubular projections *a*, *a*, the use of which tends to accelerate the circulation of the water, providing for its subdivision, so to speak, into sections or bodies of comparatively small volume, thus increasing the rapidity with which the heat is absorbed by the water in contact with the

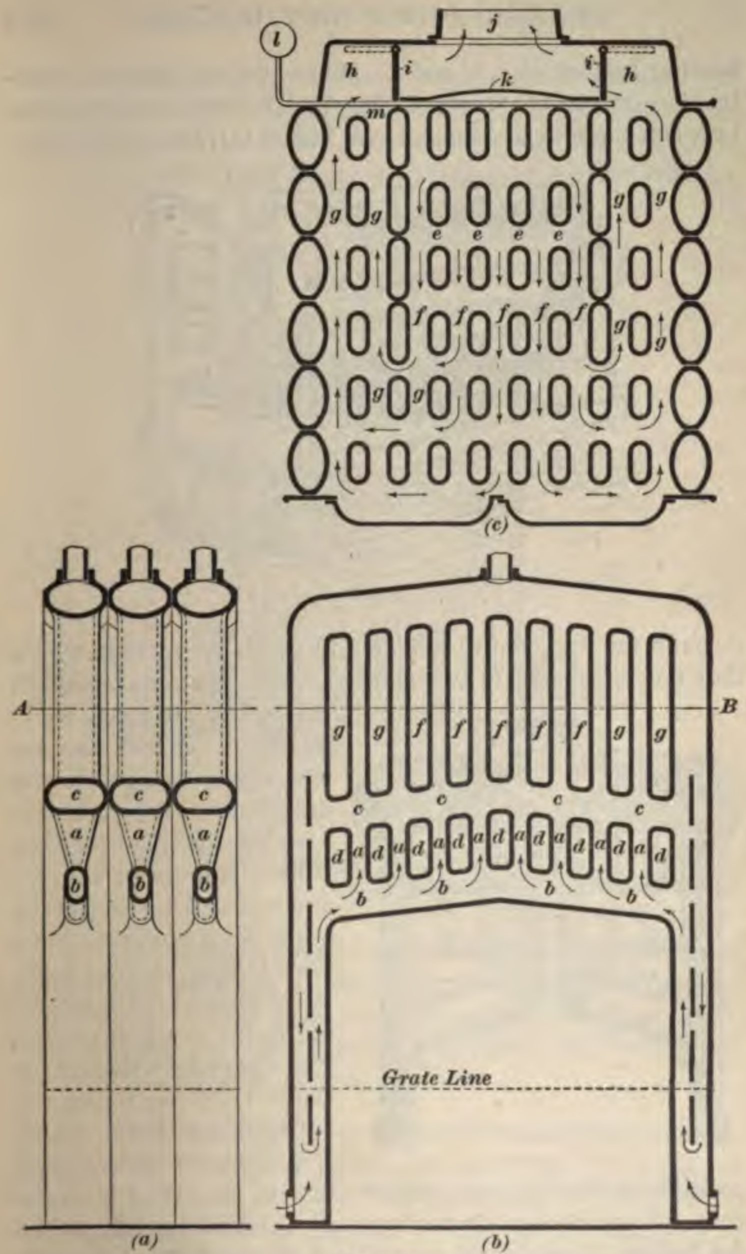


FIG. 8

heating surface of *a*, *b*, and *c*. When the hot gases of combustion reach the rear of the boiler they pass upwards between the rear sections at *e*, *e*, Fig. 8 (*c*), thence forwards

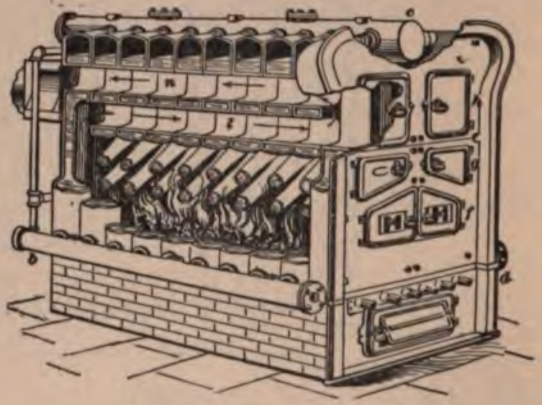


FIG. 9

through the five central flues *f*, *f* to the front section, where they are deflected into two parallel flues *g*, *g* at either side of the boiler, and travel backwards to the rear section, where they descend in the drop flues *h*, *h*, pass under around the division or baffle-plate dampers *i*, *i* and upwards to the smoke outlet *j*. An indirect down draft is thus secured when the baffle-plate dampers *i*, *i* are in the position shown. The direct-draft damper *k*, supported at the top of and between the baffle plates *i*, *i*, is shown in its closed

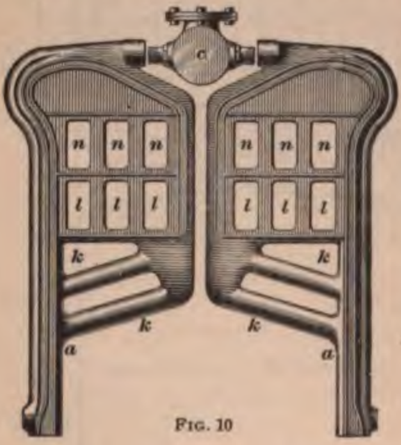


FIG. 10

position against the rear section; that is, so as to deflect the gases of combustion through the central flues to the front of the boiler. A weight *l* on the end of the damper lever *m*

holds the damper *k* in position, either open or closed. On starting a new fire the weighted lever at the damper *k* may be shifted so as to throw the damper away from the rear section and permit the gases of combustion to pass directly

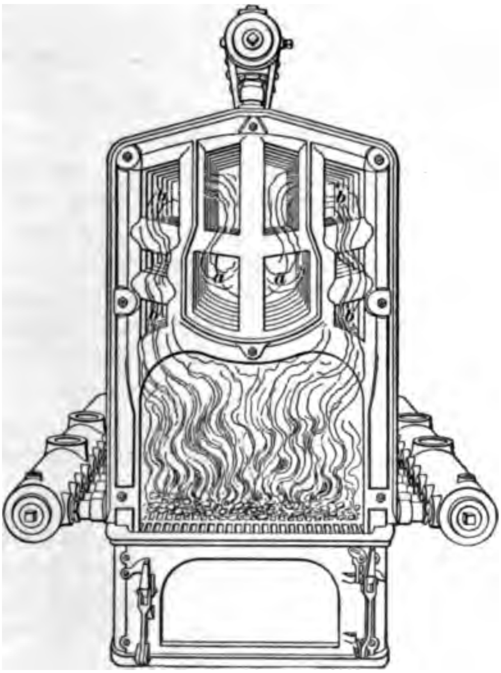


FIG. 11

to the smoke outlet without circulating through the side flues. A less direct draft may be obtained by shifting the baffle-plate dampers *i*, *i* to their open position and closing the direct-draft damper *k*. As ordinarily operated, the baffle-plate dampers *i*, *i* are kept closed, as shown.

19. Richmond Boiler.—The Richmond boiler section, as indicated by Figs. 9 and 10, is made in two parts, or halves, *a*, *a*, Fig. 10, connected by screw nipples to the steam drum *c* and to the water drums *b* and *d*, Fig. 9, at the sides of the boiler. The water circulates freely in each half section,

which is practically a small independent boiler in itself, passing up the inclined tubes *k* and descending through the channel in the outer rim of the section. The hot gases impinge on the tubes *k*, *k*, Fig. 10, and pass between them to the rear-end section. They then pass forwards to the front through the passages *l*, *l*, returning through the upper passages *n*, *n* to the smoke outlet at the rear of the boiler.

20. Gem Boiler.—The Gem boiler section, as shown in Fig. 11, has very little steam space and little internal circulation. From the grate to the steam space the sections are within the combustion chamber, tubular water-heating surface being arranged at either side of a central flue *a*, which extends from the front to the rear of the boiler. The tubular surfaces are so arranged that the gases are deflected toward the front of the boiler, entering the central flue *a* at the front section, and thence travel directly back to the chimney. After passing from the combustion chamber *b*, the gases are confined in the flue *a* around the steam portion of the boiler, the smoke connection being made at the bottom of this flue space.

21. Gurney Bright Idea Boiler.—The boilers so far described are limited in capacity, the largest being rated to supply about 3,500 square feet of radiation. For larger amounts of radiating surface, two or more boilers are frequently connected together in such a manner that during mild weather one of the boilers can be used to supply part of the radiating surface. Special sectional heating boilers are manufactured, however, for capacities greater than 3,500 square feet of radiation; they are similar in most respects to the small heating boilers, but have a different form of flue surface. An example of a large heating boiler is the Gurney Bright Idea boiler shown in Fig. 12. It is made up of cast-iron sections having circulation tubes extended into the combustion chamber and flue spaces. Each of the intermediate sections *a*, *a* is made in the form of an inverted **L**, with four or more rows of Bundy tubes *b*, *b* extending horizontally from the vertical leg. The front

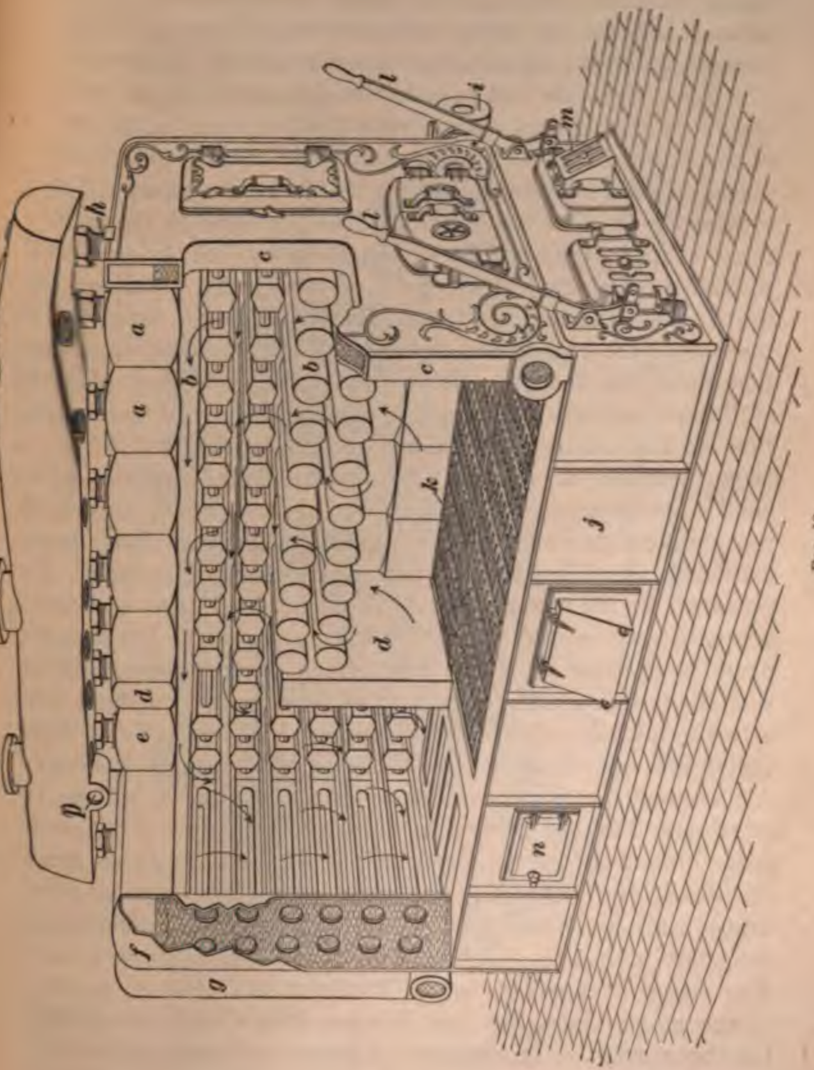


FIG. 12

section *c* is a hollow casting carrying the flue doors, fire-doors, and ash-pit doors. The upper rows of tubes have the form of a loop; the lower tubes are round, but have a diaphragm inside to insure a positive circulation of the water. The gases circulate and pass to the chimney in the direction shown by the arrows. To divide the flue space at the rear of the boiler from the firebox, a metallic sheet is sometimes placed in such a position that the course of the gases will be toward the front of the boiler, and thence through the upper rows of circulating tubes to the chimney. A bridge-wall section *d* is inserted at the back of the grates, dividing the firebox from the rear sections. This bridge wall extends to the top of the two lower tiers of the intermediate sections that form the firebox. Behind the bridge wall are placed additional sections, as *e*, having the same general construction as the other intermediate sections, but fitted with a larger number of tubes. The rear section *f* contains the smoke chamber, which has the form of a drop flue, to which the smoke-pipe connection is made. Cleaning doors are provided in this section, and a check-draft damper is arranged in the extension *g*. The front and rear sections are each cast in one piece, and are connected to the steam drum at the center of the top. Each of the intermediate sections is independently connected into the steam drum by screw nipples *h*. The water drums, as *i*, at each side of the boiler are connected to the sections in a similar manner. All sections are supported on a cast-iron base *j*, which is fitted with shaking grates *k*, operated by a lever *l* at each side. The front of the base is fitted with ash-pit doors, and additional draft doors, as *m*. The space at the rear of the bridge wall and beneath the sections forms a soot-collecting chamber, access to which is had by clean-out doors, as *n*. The steam connections can be made at one or more points of the steam drum, suitable flanges, as *o*, *o*, being provided for the purpose. Drain pipes connect the tappings of the pocket *p* in the steam drum with the two water drums, and permit any water carried by the steam into the drum to drain back.

22. Capitol-Mascot Boiler.—The form of section used in the Capitol-Mascot boiler, shown in Fig. 13, differs considerably from the sections previously described. Instead of being flat, each section *a* forms a segment of a circle.

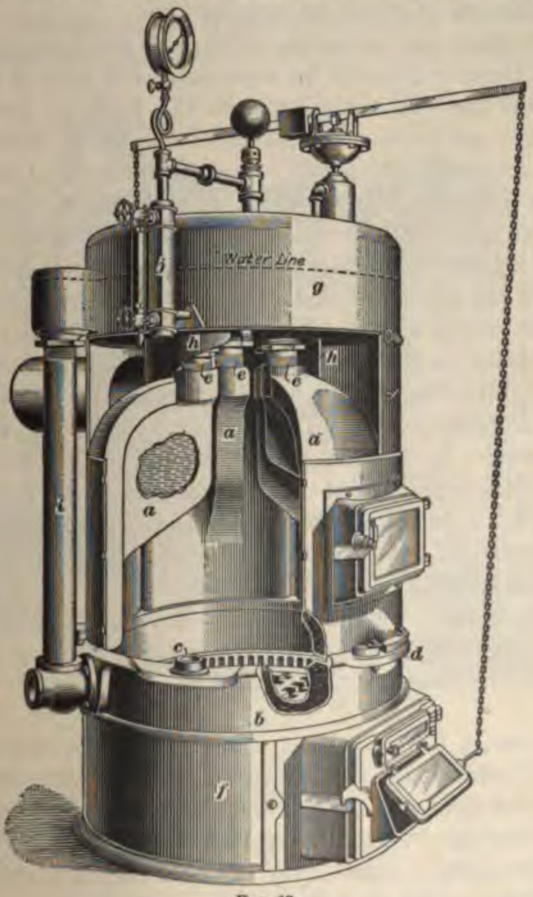


Fig. 13

There are three sections, which rest on a water ring *b*, to which they are connected by slip nipples, as *c*; the sections and the water ring are held together by bolts passing through suitable flanges, as shown at *d*. The top of each section is connected to the steam dome by long-screw

nipples *e*, *e* and locknuts. The water ring *b* rests on the ash-pit base *f*, slightly above the level of the grate, which is of the shaking type. A projection or lobe extends from the inner side of each section directly over the fire and provides a large amount of direct heating surface.

The sections are interchangeable, and there is ample play between them to provide for expansion and ease of erection. The gases pass upwards between the lobes to the center, where they strike the under side of the steam dome *g* and are deflected by baffle plates *h* toward the front of the heater and then pass around the sides and underneath the dome to the smoke pipe in the rear. The circulation of the water is vertical; there are no lateral water-courses such as are common with horizontal sections. A circulating pipe *i* connects the water ring *b* with the base of the steam dome *g*. Since this is filled with water to the level indicated, the circulation pipe is always filled with water, and being located in a relatively cold place outside of the boiler has a downward circulation within itself. It will be noticed that there is a decided difference between this circulation pipe *i* and the pipe *m* shown in Fig. 6, which is frequently referred to as a circulating pipe. The latter, however, being connected to the steam drum above the water-line, is not filled with water and does not in any way aid the circulation, but merely serves as a drain pipe. A water gauge *j* indicates the height of the water in the boiler.

23. Ideal Boiler.—The same general design and constructive arrangement is found in boilers with slip-nipple connections that obtains in boilers with screw-nipple connections. The Ideal boiler, illustrated in Fig. 14, is an example of a slip-nipple construction. The illustration shows how the slip-nipple joint is made by placing the tapered ends of nipples *a* into correspondingly tapered circular openings in the boiler sections, which are then drawn together and held tightly by through bolts *b*, *b* passing through the sections. Some of the nipples used in such boilers are made of steel, pressed to the proper form, while others are made of cast

iron, malleable iron, or brass and finished by a machine to the proper taper. The boiler has a double row of flues *c* and *d* above the firebox. The gases pass from the fire to the rear sections through openings, as *e*, thence forwards to the front through *c*, *c*, and return to the smoke chamber at the rear through the upper flues *d*, *d*. When the boiler is fitted

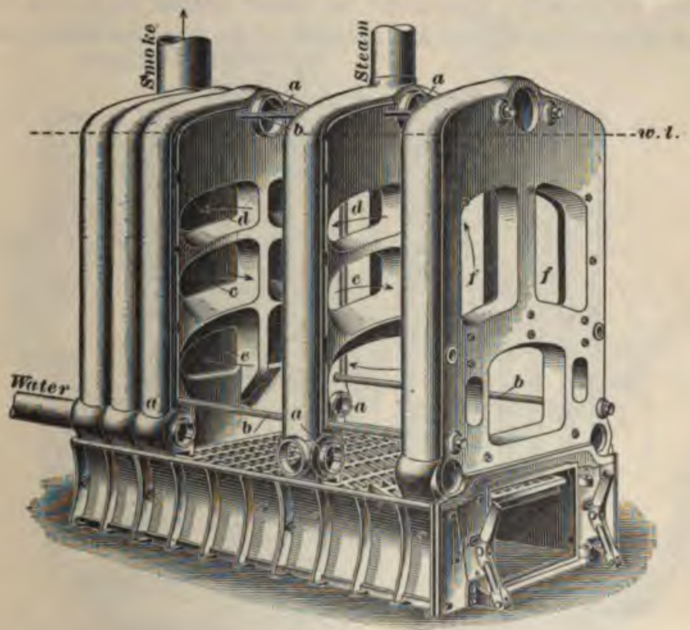


FIG. 14

up complete, the sections are connected together at the top and bottom by slip nipples. The front section is a cast-iron hollow slab having openings *f*, *f* that allow the return of the hot gases through the flues *d*, *d*, whence they pass to the smoke pipe. The sections rest on a separate cast-iron base fitted with easily removable shaking grates.

24. Capitol Boiler.—In the Capitol boiler, shown in Fig. 15, the sections are connected to the steam drum and water drums by slip nipples. Flues *a*, *a* are formed above the tubes *b*, *b*; a central return flue *c* is located below the

steam drum *d*. The rear section has recesses, as *e*, one at each side, that allow the heated gases to flow into the flues *a*, *a*. The sections are connected at the top to the horizontal steam drum by slip nipples, as *f*, on each side of the drum, and are drawn together by bolts *g* that pass through lugs cast on the top of each section and on the steam drum, as shown. The water or return drums, as *h*, one on each side of the heater, are secured to the base on which the

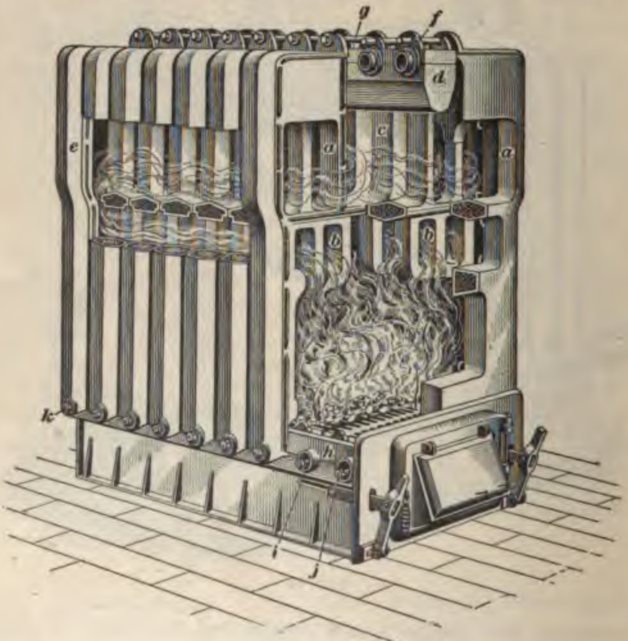


Fig 15

boiler rests. The water leg of each section is connected to the drum by a slip nipple *i* secured by means of bolts, as *j*, screwed into tapped sockets inside of *h*. The water legs are drawn up tight on the slip nipples by the nuts *k*, with some form of packing to make a tight joint between the nut and the casting. The base is fitted with shaking grates, with the necessary attachments, clean-out doors, and check-draft. The steam main for the radiators is connected to the steam drum

at the top, the return connections from the radiators being made into the rear end of each return header.

25. Bundy Boiler.—The Bundy boiler shown in Fig. 16 has the firebox inside of the sections. The intermediate sections forming the combustion chamber are fitted with shaking grates. Behind these sections is placed a hollow

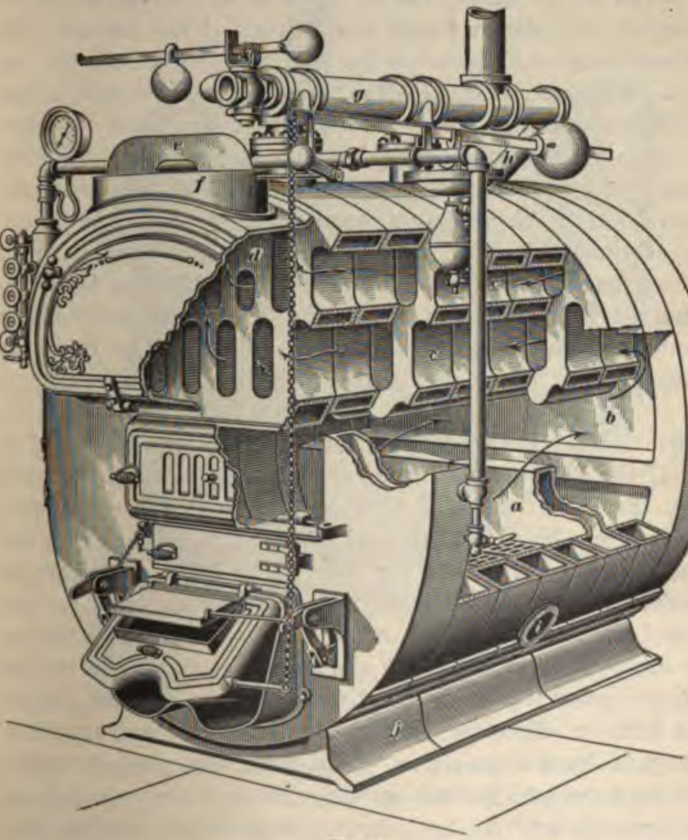


FIG. 16

bridge-wall section *a*, back of which the rear combustion chamber is formed by a recess *b* in the rear section; or, in the larger boilers, by the addition of an intermediate section somewhat like the ones over the grate. The recess *b* is

continued up high enough to enable the gases to enter the flues *c*, *c*, through which they pass to the front, into a smoke chamber *d* bolted to the front section, and fitted with a damper *e* and a collar *f* for a smoke-pipe connection. A large flue door is fitted to this chamber for cleaning the flues. The sections are held together by long bolts passing through the center of the section at the top and also at the center of the water leg, which forms the bottom of the ash-pit, slip nipples being used between the sections. Openings for the steam-supply connection for the radiators are provided at the top of one or more sections, which are then yoked together by a wrought-iron pipe *g* serving as a steam drum. A circulating pipe *h*, which is really a drain pipe, is carried from the steam drum to the return outlet at the bottom of one of the rear sections. Return outlets, as *i*, are provided at each side of the boiler in one or more sections. The boiler is supported in a cast-iron cradle *j*. The large combustion chamber at the rear and the accessibility of the flues for cleaning adapt this boiler to burning bituminous coal.

26. Model Boiler.—In the type of boiler illustrated in Fig. 17 the sections are placed at right angles to the furnace front, instead of parallel to it, as in most other designs. The sections have the general form of an inverted **L**, the water leg being placed to the rear. The legs are connected together by push nipples, and have a cylindrical enlargement at the bottom to form the return header or water drum *a*. The sections have a deep **V**-shaped projection *b* extending from the water leg to the front of the boiler. These projections form the direct heating surface, and have corrugations, as *b'*, that form flues *c*, *c* in which the gases pass forwards from the combustion chamber through the lower set of flues, and then backwards to the smoke chamber at the rear through the upper flues. The steam space is above the water-line *w l*. The sections are connected together at the top by slip nipples placed near the center of the top, as at *d*, and are held together by long through bolts. The boiler front *e* is hollow, filled with water, and connected to the

steam space and water space of the boiler by pipes to insure a circulation of the water. A cast-iron smokebox *f* at the rear, fitted with a smoke-pipe collar, connects all the return flues (the upper flues *c*) to the chimney. A check-damper is placed at *g*, and a clean-out door *h* gives access to the flues.

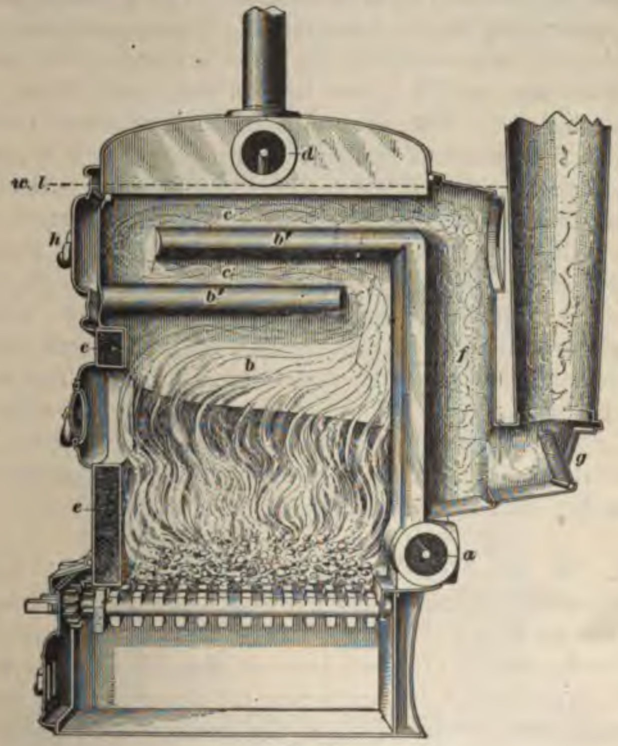


FIG. 17

27. Brick-Set Sectional Boilers.—Boilers having their sections enclosed in a brickwork setting are similar in general construction to the self-contained, also called **portable,** types, previously described. They are usually provided with an ornamental cast-iron front fitted with fire, flue, and ash-pit doors, and frequently have a deflection plate above the fire-door to compel the heated gases to pass over the bridge wall to the rear of the boiler, and thence through the

lower flues to the front, returning to the smoke pipe at the rear of the boiler through the upper flues. The rear deflecting arch is commonly fitted with a direct-draft damper, so that the heated gases, in order to quicken the fire, may be allowed to pass directly to the chimney without passing through the flues. The setting is usually of a double row of brick, but may be thicker, as required. Cast-iron binding bars and tie-rods are provided to bind the brickwork, and clean-out doors are usually placed in the side wall of the rear smoke chamber. The side walls are built up above the top of the sections and roofed over with brickwork, or iron plates, or, the irregularities of the castings of the upper part of the sections are made tight by the usual method of puttying the joints. In erecting the brick-set type of boiler, the sides of the firebox and the top of the bridge wall should be lined with a good quality of firebrick. Circulating pipes similar to those described in connection with portable forms, should be fitted between the steam and water drums. The small sizes of heating boilers are seldom set in brick; they are usually of the portable type. Large sizes, however, are frequently set in brickwork, principally for the purpose of preventing excessive loss of heat from them.

28. In the Mills brick-set cast-iron sectional boiler, shown in Fig. 18, the sections are tube-shaped, being somewhat similar to manifold coils; the steam space *a* in the upper part of the sections is quite large in proportion to the water space. The tubes *b*, *b* directly over the fire are bent or turned in such a manner as to allow the upward currents of the steam and water to circulate freely, the steam separating from the water in the large tubes *c*, *c* and thence passing through *a* to the steam header *d*, the water passing down the outside tubes *e*, *e*; this insures a free internal circulation in each section. The sections are made in two pieces, or halves. A rib is cast on the tubes *c*, *c* just below the water-line *w l*, so that the heated gases rise to this point and thence are deflected down between the sections and around the downward circulation tubes *e*, *e*; thence the gases drop into return

flues *f* formed in the brickwork, beneath the sections. The two half sections are joined at the top to the steam header by screw nipples *g*, *g* at each side, the return headers *h*, *h* being connected to the bottom of each half section by screwed nipples *i*, *i*. The sections rest on a cast-iron plate *j* that is perforated to allow the gases to pass into the brick flue space. The shaking grate is placed in an iron framework

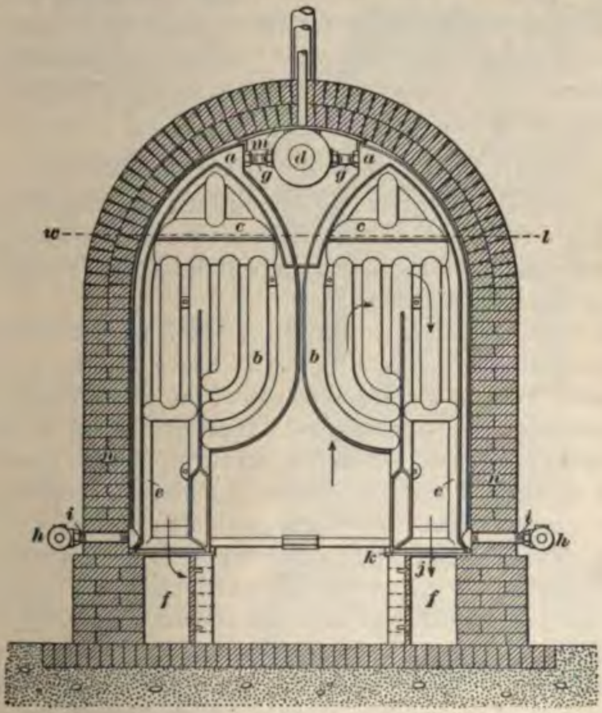


FIG. 18

set on *k* and is operated by a lever. An iron shield *m* is placed over the steam drum, on which the brick roofing of the boiler may rest, enclosing the boiler at the top, but allowing facilities for making repairs to the steam header. The brickwork *n* at the sides is usually built 8 inches thick for small boilers. Large boilers should have 12-inch walls. The smoke flues *f*, *f* under the boiler connect at the rear into

a covered chamber having a cast-iron plate to which the smoke connection is made.

Where the chimney draft is poor, it is especially desirable to utilize the surface of the outer tubes of the sections as heating surface. This can be done by building the brick walls so as to provide a space of 4 inches around the tubes *e, e* up to the water-line of the boiler. The smaller sizes of the Mills boiler have one-piece, full-width sections, with a single connection to the steam drum for each section, the boiler being covered in with roofing bars and plates, or with brickwork. The very large types of this boiler have two separate fireboxes.

HORIZONTAL-SECTION HEATING BOILERS

29. Premier Boiler.—Although the majority of heating boilers are composed of vertical sections, there are a number of designs of small heating boilers in the market having their sections placed horizontally.

The Premier boiler, shown in Fig. 19, is an example of the horizontal-section circular type. It has a fire-pot section *a* with corrugations around the inside, the water being made to circulate through passages *b* that extend to a central chamber, and thence through a screw nipple *c* to a slab-like disk *d* in which there are circular openings for the passage of the gases. The water then passes to the next section above, which is secured by a screw nipple to the lower section, thence passing to the dome *e* in which there are flues *f* that permit the gases to pass into the smoke chamber *g* above, which is fitted with a check-damper and smoke-pipe collar and damper. In order that the gases may impinge on all the sections, the flue openings therein are staggered, as shown. The flue spaces around the sections are closed by cast-iron bands *h*, which are bolted in position, the joints being made tight with furnace putty. Boilers of this type are useful only for small jobs; they cannot be forced beyond their rated capacity, owing to poor internal circulation.

30. All Right, Volunteer, and Jewel Boilers.—The All Right and Volunteer heating boilers belong to the same

general class as the Premier boiler, shown in Fig. 19. The All Right boiler is set in brick; the Volunteer boiler is self-contained, or of the portable form, as it is usually expressed. The sections greatly resemble a cart wheel, the tubes and waterways being analogous to the spokes and rim of a wheel. The portable boiler has an iron jacket that encloses the flue space around the sections; this jacket is lined with asbestos. The brick-set form allows the gases to pass around the water leg, thereby increasing the area of the surface in contact with the heated gases.

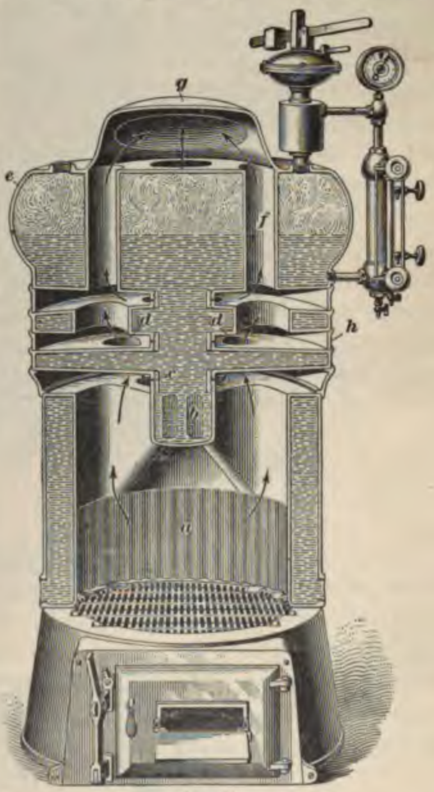


FIG. 19

Horizontal-slab sectional boilers with slip-nipple connections are made similar to those having screw-nipple connections. An example of a horizontal-slab slip-nipple-connection sectional boiler is the Bundy Jewel boiler, which has an extension at the back to form the flues of the smoke chamber. This extension has a waterway into which a short slip nipple is placed by means of which the sections are connected together.

31. Florida Boiler.—The Florida boiler, shown in Fig. 20, is a boiler with a magazine feed and having cast-iron sections shaped as shown in Fig. 21. The sections have packed joints between them. The water passes from one

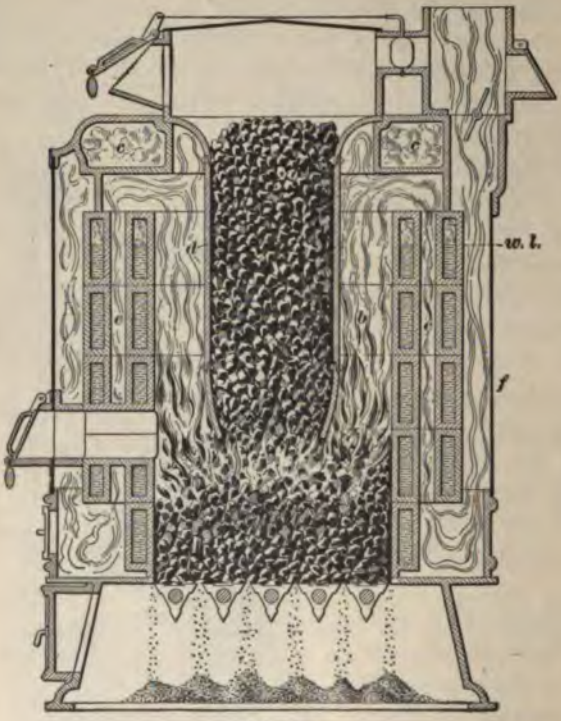


FIG. 20

FIG. 21

section to another through the openings *a*, Fig. 21. The several sections are bound together by bolts, which pass up through these openings, and the joints are made water- and steam-tight by means of asbestos gaskets or other suitable packing. The inner edge of each ring is corrugated, as shown at *b*, Figs. 20 and 21, so as to secure a large amount of heating surface. The water level is maintained about at the line *w l*. The top section *c*, Fig. 20, serves as a steam drum. The hot gases pass upwards between the inner faces of the sections and the magazine *d*, Fig. 20, and descend through the passages *e*, Figs. 20 and 21. They then pass upwards again between the outer faces of the sections and the jacket *f*, Fig. 20.

The Florida boiler can be obtained without a magazine feed, and in this pattern greatly resembles the one shown, except that the corrugations *b*, Fig. 20, of the sections extend farther inwards and thus give more direct heating surface over the fire.

TUBULAR HEATING BOILERS

DROP-TUBE BOILERS

32. Construction of Drop Tubes.—Boilers in which the largest part of the heating surface is given by tubes, are known as **tubular boilers**. Such boilers are divided into two general classes: Those that have the hot gases passing through the tubes are called **fire-tube boilers**, while those that have water on the inside of the tubes and hot gases on the outside are called **water-tube boilers**.

33. A certain form of fire-tube steam boiler has a number of wrought-iron or cast-iron tubes projecting downwards from a hollow casting at the top into the firebox directly over the fire, the tubes thus being exposed to the radiant heat of the fire and surrounded by the hot gases of combustion. Boilers thus constructed form a class known as **drop-tube boilers**. In order to secure unimpeded circulation in these depending pipes, they may be fitted with inner

circulating tubes, as shown by Fig. 22. Steam is rapidly generated on the inner surface of the tube *A*, and the mingled steam and water flow swiftly upwards. A return current of water flows downwards through the tube *B*. The inner tube merely serves as a partition between the ascending and descending currents, and prevents them from interfering. If it were absent, the steam would be liable to form large

Fig. 22

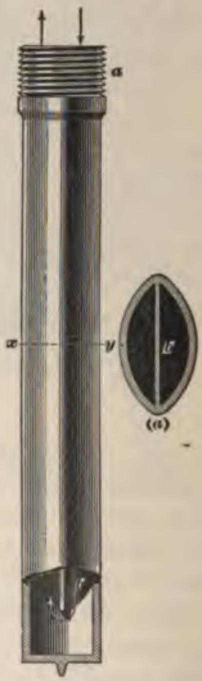


Fig. 23

bubbles, which would completely fill the bore of the drop tube, and these would lift the water out of the tube in escaping. The water would then surge back into the hot tube and be again expelled by another rush of steam. The production of steam would thus be very spasmodic, and the tubes would soon be destroyed; besides, annoying hammering and snapping noises would occur.

Cast-iron drop tubes, such as shown in Fig. 23, are used in some boilers. The threaded end *a* is screwed into the bottom plate of the top casting, which plate is often called the **crown sheet.** The tube is divided into two channels by a partition *b* that extends nearly to the bottom. The water ascends in the channel at the hottest side of the tube and flows downwards in the opposite channel. Fig. 23 (*a*) gives a cross-section of the tube on the line *x y*.

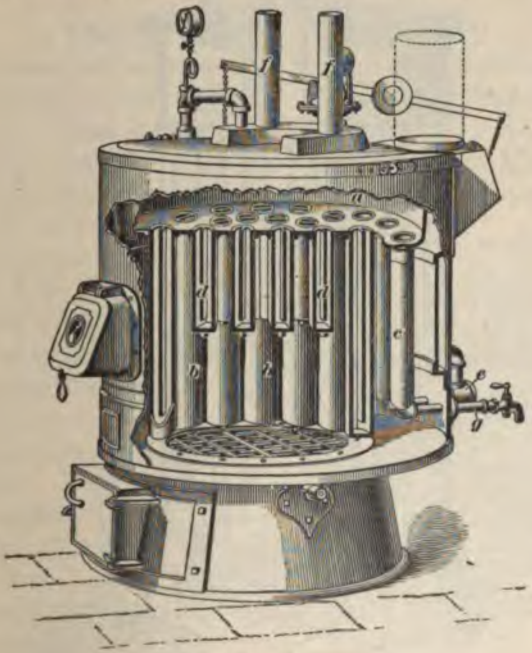


FIG. 24

34. Furman Drop-Tube Boiler.—The heating boiler illustrated in Fig. 24 has the cast-iron drop tubes shown in Fig. 23. It consists of a steam chamber *a* from which depend the drop tubes *b*, *b*, *c*, and *d*, *d*. The long tubes *b*, *b* are spaced close together and enclose a circular fire-space and combustion chamber. The short tubes *d*, *d* are separated sufficiently to allow the hot gases to circulate freely among them. The feedwater is introduced into one of the

rear tubes *c* through the pipe *e*, and the steam is taken off by the pipes *f*, *f*. The pipe *g*, fitted with a cock, is the blow-off pipe through which the boiler is emptied.

35. Nason Boiler.—The boiler shown in Fig. 25 is substantially composed of a number of vertical tubes screwed

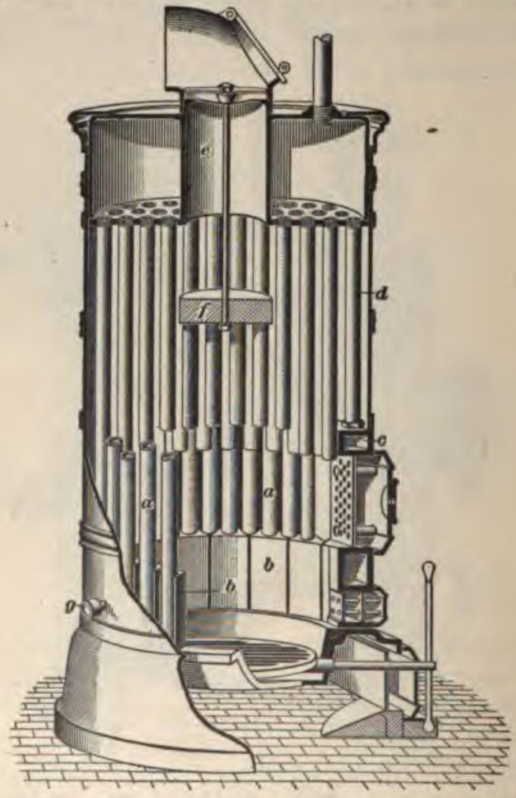


FIG. 25

into a cast-iron dome. The outer tubes *a* form the fire-pot by passing down to the cast-iron base, where firebrick, shaped to fit between the tubes, is inserted, as at *b*. The fire-door opening is in a cast-iron water box *c* into which shorter tubes *d* are screwed. A flue opening *e* is provided for the smoke to pass through the steam dome and into the smoke

pipe. A deflector *f* causes the gases to pass between the tubes that are over the fire. The drop tubes are provided with a diaphragm inside, the circulation of the water being down one side of the diaphragm and up the other side. The steam connection for the radiation is made to the dome at the top, the return pipes from the radiators being connected to one or more of the outside drop tubes, as at *g*.

WATER-TUBE HEATING BOILERS

36. Box-Coil Boiler.—A heating boiler composed of pipes and fittings, the water being inside the tubes, is shown in Fig. 26. From its similarity to the box coil used formerly to a large extent in steam heating, it is called a **box-coil boiler,** and like the box coil, has become almost obsolete. It consists of two mud-drums *a*, *a* and water drums *b*, *b*, to which are connected a series of inclined zigzag tubes *d*. Each alternative tube is connected to the drums on the opposite side of the boiler. The water flows upwards from the mud-drums through the inclined tubes to the water drums, and descends through the large vertical return pipes *e*, *e*. Steam collects in the steam drum *c*. The furnace may be placed under the boiler, or it may be placed at one end and the gases be moved horizontally, thus enabling the boiler to be used in places having low ceilings. The boiler is enclosed in plain rectangular brick walls, and may be set in almost any position desired. The arrangement of the heating surfaces is such that steam is made very rapidly.

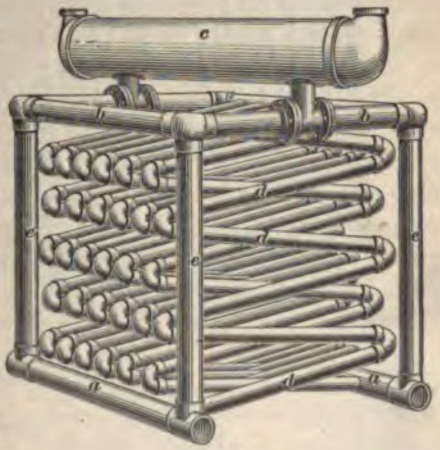


FIG. 26

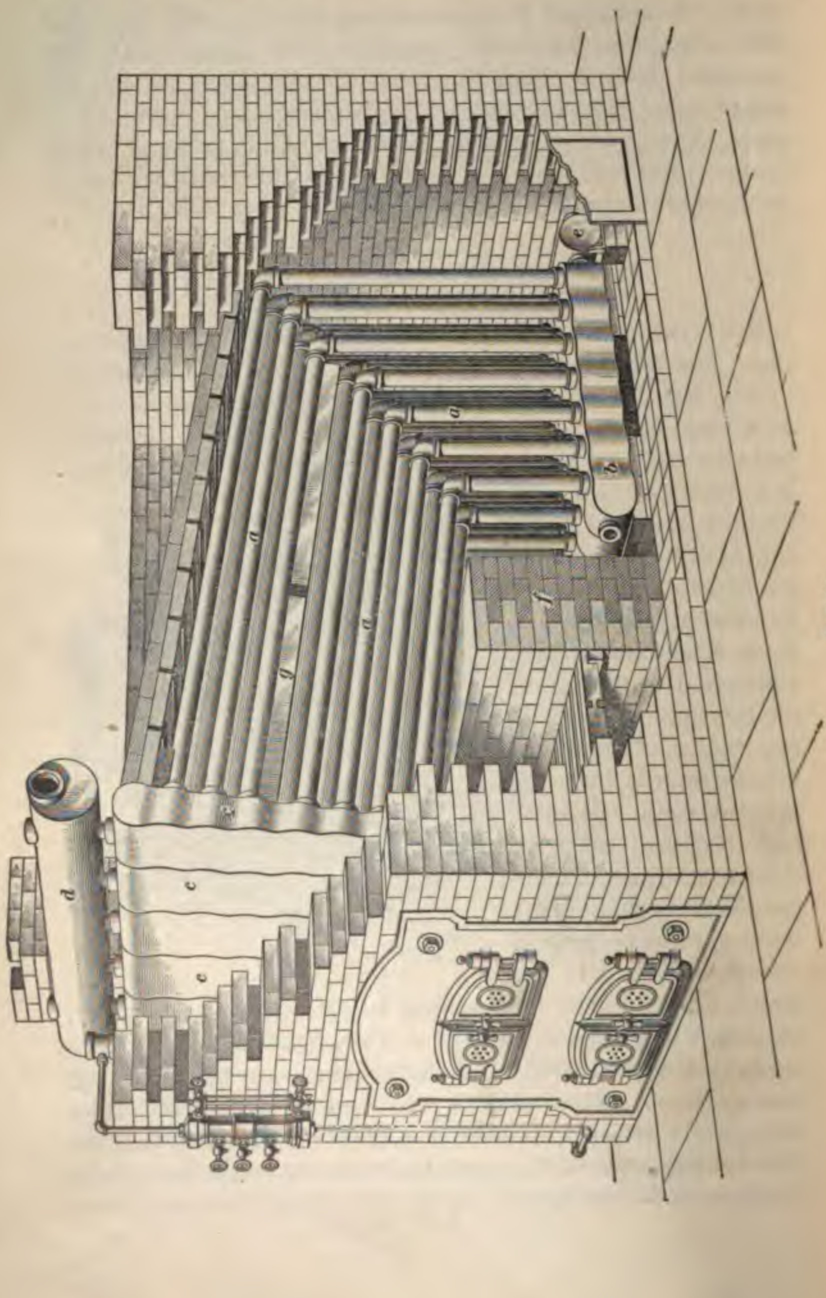


FIG. 27

37. Rutzler Boiler.—The Rutzler sectional heating boiler, as shown in Fig. 27, is a water-tube boiler having its heating surfaces composed chiefly of pipes. It consists of a series of vertical and horizontal 2-inch pipes *a*, *a* united by elbows and screwed into corrugated cast-iron manifolds *b* and *c*. The tubes are staggered in order to cause the gases to pursue a zigzag path, which retards their passage to the chimney and at the same time causes a more intimate contact with the tubes; this results in a greater absorption of heat from the gases than would obtain otherwise. The corrugated headers *c*, *c* at the front of the boiler are connected to the steam drum *d* by screw nipples having right-and-left threads, the bottom headers *b* being connected to a mud, or return, drum *e* with long-screw nipples and locknuts. Openings are provided in these drums for the steam, feed, and blow-off connections. The front headers rest in a saddle, while the rear headers rest on friction plates to allow for expansion. The boiler is set in brickwork, which serves to support the grates. The bridge wall *f* back of the grate is carried up to the tubes. A fire-deflecting plate *g* is placed between the upper and lower sets of tubes, causing the hot gases to pass between the lower tubes, to the rear, and then between the tubes of the upper rows to the chimney connection, which is usually placed near the front. The top of the boiler is covered in with brickwork or tiles supported by T bars. The brickwork is bound together by buckstaves and tie-rods.

The Rutzler boiler can be used for medium pressures for power as well as heating. In some cases it is advisable to increase the steam space and carry the water level higher, thus adding to the capacity of the boiler. In such cases the front drum is connected by two large tubes to a steel drum placed at the rear, the water-line being about at the center of the drum, which is connected by two return pipes to the bottom headers to allow for circulation. In this construction, the smoke pipe is connected to the rear under the steam drum.

SHELL HEATING BOILERS

38. Dry-Tube Shell Boiler.—Shell heating boilers consist of a shell made of steel or wrought-iron plates, generally cylindrical in form. The types of shell boilers used for low-pressure heating work generally have a cylindrical firebox, made of steel plate, within the shell. A large heating surface is given by tubes through which the gases pass. An example of a fire-tube vertical shell boiler is given in Fig. 28. It has a cylindrical firebox inside the shell. Short tubes pass from the top of the firebox to the top head of the shell, as shown. The hot gases, after passing through the tubes, pass downwards over the outer surface of the shell, and are allowed to escape through an outlet Q near the bottom. The smokepipe leading to the chimney is connected to the outlet Q. The jacket S consists of a metal shell, which is lined with non-conducting and refractory material. An inclined partition, or baffle plate, P extends around the boiler to the point X, compelling the gases to pass over nearly the whole outer surface of the boiler shell. The heating surface is thus considerably increased. The upper part of the tubes is not surrounded by water, or is dry, as it were. From this fact the boiler is said to belong to the **dry-tube** type.

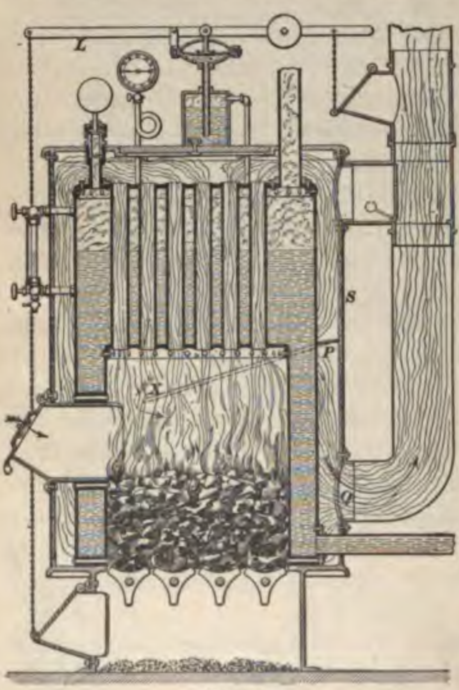


FIG. 28

39. Dunning Boiler.—The Dunning boiler, illustrated in Fig. 29, has two cylindrical shells *a* and *b*, of which the inner shell *a* forms the firebox and combustion chamber. The upper part of the combustion chamber is enlarged, as shown at *c*; a series of vertical fire-tubes, as *d*, connects this enlarged part with the bottom head of the boiler. The gases pass downwards through these tubes and up around the outer shell, a deflector or baffle plate *e* causing the gases to pass entirely around the outside of the shell before reaching the opening *f* to the chimney. The boiler is enclosed in brickwork, as shown. Since the tubes are surrounded by water throughout their whole length, or submerged, as it were, the boiler belongs to the **submerged-tube** type.

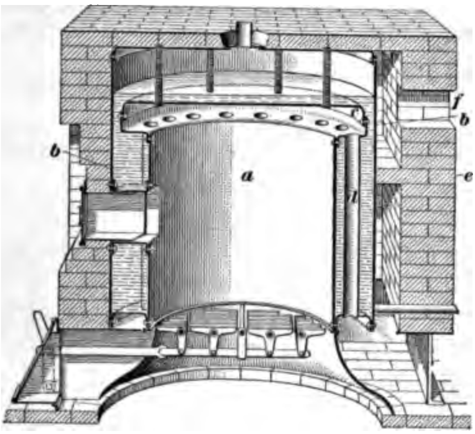


FIG. 29

POWER BOILERS

SHELL POWER BOILERS

PURPOSE AND DIVISION

40. Power boilers are those that generate steam for use in driving engines, and for operating other machinery. The pressure carried in power boilers is therefore much higher than that required only for heating purposes, and power boilers are consequently constructed of such materials and in such a manner that they will resist the greater internal pressure.

The extensive heating systems of large manufacturing establishments require the use of boilers primarily intended for the generation of steam for power purposes; the general design and construction of the boilers commonly employed only for heating are such as to limit their use to buildings of comparatively small size.

Power boilers occupy a prominent place in the heating of large office and other public buildings, state and federal institutions, such as asylums, jails, court houses, etc., and in theaters, hospitals, schools, etc., where, in many cases, they furnish steam for heating only. Whenever power is necessary, however, the boilers can be used to supply steam for the heating system as well, a steam pressure suitable for the power-generating apparatus being carried on the boilers, and reduced to a pressure suitable for the heating system by means of a reducing valve.

41. Power boilers may be divided into fire-tube, water-tube, and sectional boilers. Fire-tube boilers always have the tubes enclosed by a shell, made of wrought iron or steel plate, and hence are often called **shell boilers.** The ordinary types are either horizontal or vertical.

MATERIALS OF CONSTRUCTION

42. The materials used in modern power boiler construction are *wrought iron*, *steel*, *cast iron*, and, to a very limited extent, *copper* and its alloys. The qualities required of boiler material are: (1) Ductility, in order that it may undergo, without injury to its tensile strength, the various processes to which it must be subjected in being made up into boiler parts; (2) tensile strength, to resist the stresses due to the steam pressure; (3) toughness and elasticity.

43. Wrought iron, until a few years ago, was almost the only material of which boiler shells, fireboxes, and tubes were made. The wrought iron used in the better grade of work is known commercially as *C H No. 1 flange iron*. This has a tensile strength of from 50,000 to 65,000 pounds per square inch and is quite homogeneous; that is, it has an even texture. This grade of iron is not very fibrous, does not blister nor crack much in the fire, stands repeated heating, and flanges well. When the iron is made to have the higher tensile strength, it is usually found to be obtained at the sacrifice of ductility. As a measure of ductility, good boiler iron should show an elongation of at least 20 per cent. in a length of 8 inches; that is, when a bar 8 inches long is placed in a testing machine, it should stretch $8 \times \frac{20}{100} = 1\frac{6}{10}$ inches before breaking. Iron used for rivets should be of the very best quality; it should be soft and tough; the tensile strength should not exceed 50,000 pounds per square inch; and a good rivet should bend double while cold without fracture.

44. Steel has today supplanted wrought iron almost entirely as a boiler material. The steel used in boiler construction belongs to the class known as soft or mild steel and is nearly always made by the Siemens-Martin process, more commonly called the "open-hearth process." It exceeds iron in tensile strength, thus permitting the use of thinner sheets; it is as ductile as, and more homogeneous than, iron, and by the modern processes it can be manufactured more cheaply.

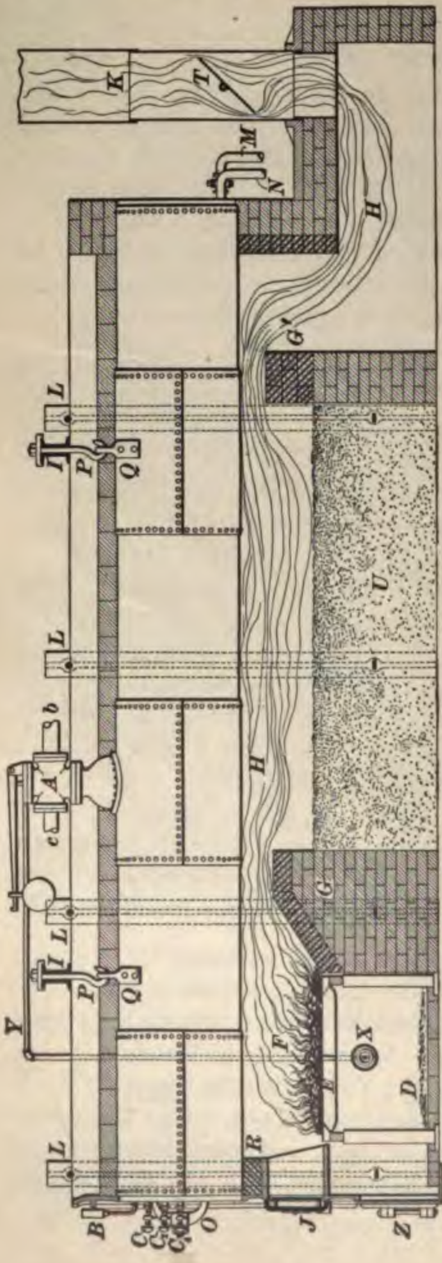


Fig. 30

45. Cast iron is used only in sectional boilers like the Harrison, and in these cases steel castings are often substituted for it. Cast iron has some advantages as a boiler material. It is cheap, durable, and will withstand corrosion better than wrought iron or steel. Its brittle and treacherous nature, however, should prohibit its use in high-pressure boilers, except for mountings and settings. Sometimes, however, the ends or heads of plain cylindrical and flue boilers are made of heavy plates of cast iron.

HORIZONTAL SHELL BOILERS

46. Plain Cylindrical Boiler.—The simplest form of shell boiler, from which all other types of horizontal shell boilers have been developed, is the plain cylindrical boiler shown in

Figs. 30, 31, and 32. Its use is very limited today, it being scarcely ever found outside the coal-mining regions of the United States of America, and even there it is becoming scarce. It consists essentially of a long cylinder, called the **shell,** made of iron or steel plates riveted together as shown in Fig. 30. The ends of the cylinder are closed by flat or hemispherical plates called the **heads** of the boiler. The front head is shown in Fig. 31, carrying the fittings B, C, C_1, and C_2. In this type of boiler the heads are often made of thick cast iron, though wrought-iron plate may

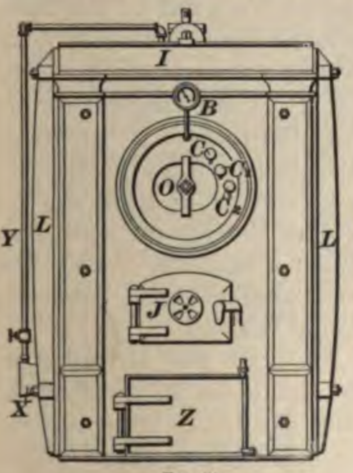


Fig. 31

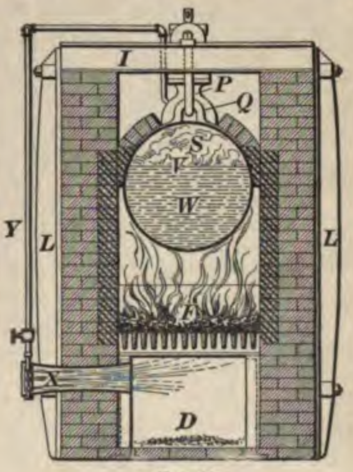


Fig. 32

be used. The hemispherical, or dished, form of head is stronger than the flat head, and is therefore generally employed.

The boiler is enclosed by side walls of brick. The channel beams I, I are laid across the brick side walls, and from these beams the boiler is suspended by means of the hooks P, P and eyes Q, Q (see Figs. 30 and 32), the latter being riveted to the shell. The side walls are supported and prevented from buckling by the binders, or buckstaves, L, L bolted together at the top and the bottom. The buckstaves are cast-iron bars of **T** section, as shown in the figure. The eyes Q, Q are placed about one-fourth of the length of

the shell from each end. This method of suspending the shell allows it to expand and contract freely when heated or cooled.

The rear end of the shell is enclosed by the rear wall, as shown in Fig. 30; the wall is continued back, forming the chamber *H*, into which opens the chimney, or stack, *K*. The front of the boiler, shown in Fig. 31, is of cast iron. The front end of the shell rests on the firebrick *R*. The weight of the shell comes on the hooks *P*, *P*, the rear wall and firebrick *R* simply keeping it in position.

The furnace *F* is placed under the front end of the boiler shell. The fuel is thrown in through the furnace door *J*, and burns on the grate *E*, the ashes falling through the grate into the ash-pit *D*. To insure a supply of air sufficient for the complete combustion of the fuel, the furnace is sometimes supplied with the blower *X*; this consists of a cylinder leading into the ash-pit, into which is led a jet of steam through the pipe *Y*. The jet escapes into the ash-pit with great velocity, and carries along with it a quantity of air. The blast is caused to impinge against the grate *E*, thus producing a rapid and complete combustion of the fuel.

Behind the furnace is built the brick wall *G*, called the **bridge.** It serves to keep the hot gases in close contact with the under side of the boiler shell. As boilers of this type are generally quite long, a second bridge *G'* is usually added. The gases arising from the combustion of the fuel flow over the bridges *G* and *G'* into the chamber *H*, and escape through the chimney *K*. The flow of the gases is regulated by the damper *T* placed within the chimney. The space *U* between the bridges is filled with ashes or some other good non-conductor of heat. The door *Z* in the boiler front gives access to the ash-pit for the removal of the ashes. The tops of the bridges, the inner surface of the side walls and rear wall, and in general all portions of the brickwork exposed to the direct action of the hot gases are made of firebrick (shown in Figs. 30 and 32 by the dark section lining), since the firebrick is able to withstand a very high temperature.

It will be seen, by referring to Fig. 32, that the upper portion of the boiler shell is covered with firebrick in such a manner as to prevent the hot gases from coming in contact with the shell above the water-line *V*. It is a general rule in power-boiler construction and setting that *under no circumstances should the fire-line be carried above the water-line.* The top of the shell is covered by brickwork or some other nonconducting material to prevent radiation of heat. The shell is filled with water through the feed-pipe *N*, which leads to a pump or injector. When in operation, the water stands at about the level *V*, the space *S* above being occupied by the generated steam. The safety valve is shown at *A*. The office of the safety valve is to prevent the steam pressure from rising above the desired point. The pipe *b* is the main steam pipe leading to the engine; the pipe *c* provides for the escape of the waste steam when the safety valve blows off. The steam gauge *B* indicates the pressure of the steam in the boiler. The gauge is attached to a pipe that passes through the front head into the steam space. The gauge-cocks C, C_1, and C_2 are placed in the front head of the shell; they are used to determine the water level. For instance, if the cock C_1 is opened and water escapes, it is evident that the water-line is above the cock C_1, while if steam escapes the level must be below C_1. The manhole *O* is simply a hole placed in the front head through which a man may enter and inspect or clean the boiler. The hole is closed by a plate and yoke. To permit the boiler to be emptied, it is provided with a blow-off pipe *M*, through which the water or sediment may be discharged. These boilers are made from 30 to 42 inches in diameter, and from 20 to 40 feet long, though, in rare instances, they have been constructed with a diameter of 48 or more inches, and a length of 60 or even 100 feet.

Plain cylindrical boilers, on account of their small water-heating surface, are very uneconomical, and hence are not used where fuel is expensive. They are not adapted for use in office buildings, or wherever floor space is valuable, on account of their great size and high cost of operation.

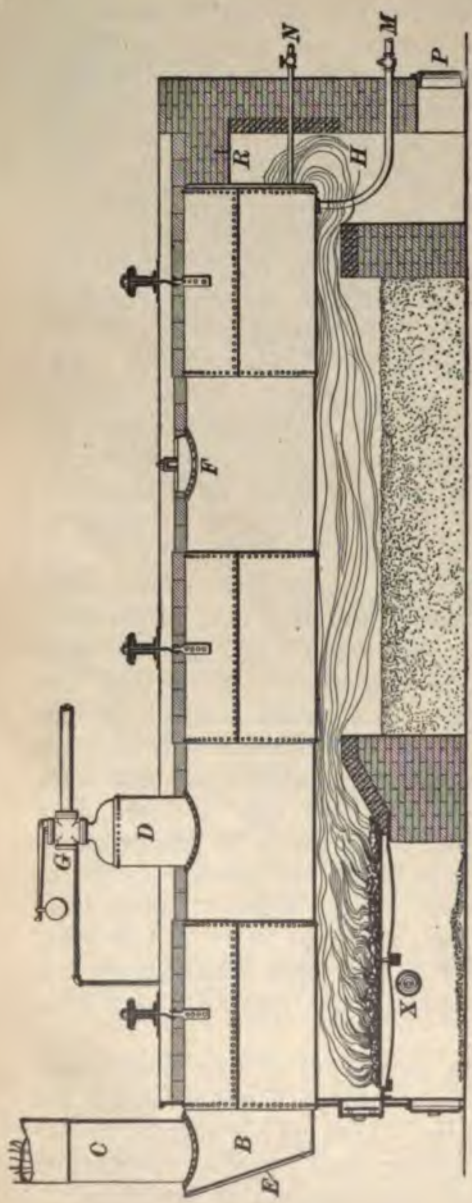


FIG. 33

47. Flue Boiler. The flue boiler has been developed from the plain cylindrical boiler by placing inside the boiler two or more large flues running lengthwise and below the water-line, thus extending the heating surface. It has the disadvantages of the plain cylindrical boiler, but to a smaller extent; since it is more accessible for cleaning than some of the more highly developed forms of fire-tube boilers, its employment is quite general in places where the feedwater is muddy, or where skilled attendance is difficult to obtain. The flue boiler, while rarely met with in the eastern part of the United States of America, is quite common in the western and southern parts.

A two-flue boiler is shown in Figs. 33, 34, and 35. The flues *A*, *A* are fixed at

the ends in the front and rear heads of the shell, respectively. The front end of the shell is prolonged, forming the smokebox *B*, into which opens the smokestack *C*. The front of the smokebox is provided with a door *E*. The boiler shell is also provided with the dome *D*, which forms a chamber where steam may collect and free itself from its entrained water before passing to the engine. The hot gases pass

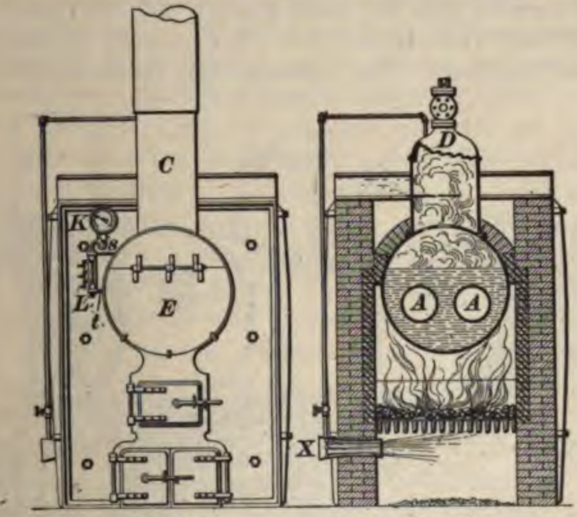


FIG. 34 FIG. 35

over the bridges to the chamber *H*, and then back to the front end through the flues *A*, *A* into the smokebox *B*, and out through the stack *C*. It is plain that the water-heating surface is increased over that of the plain cylindrical boiler by the cylindrical surface of the flues *A*, *A*. In other particulars, the description of the plain cylindrical boiler applies equally well to the flue boiler.

48. Horizontal Return-Tubular Boiler.—By extending the principle of the flue boiler, that is, by making the flues more numerous and smaller, the horizontal return-tubular boiler has been developed. In this boiler, by far the greatest amount of the total heating surface is given by the small flues, called **tubes**, that are traversed by the gases of

combustion. The space occupied is moderate in comparison with a flue boiler of equal steam generating capacity, although greater than required for water-tube boilers. When properly constructed and operated, it is a very efficient boiler that has long been a favorite for office buildings, in spite of the drawback that the large amount of water it contains makes it a very dangerous apparatus in case of an explosion. It is but recently that the more modern and inherently safer types of water-tube boilers have commenced to supersede it in office buildings. The return-tubular boiler is so largely

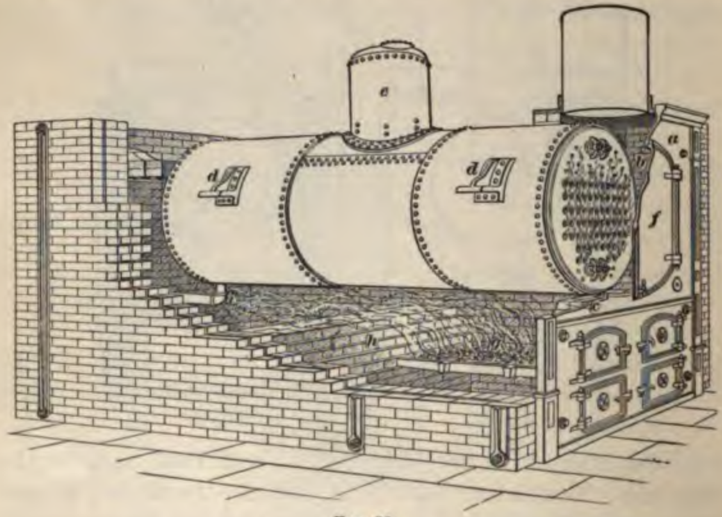


FIG. 36

used in the United States of America that it can aptly be designated as their standard fire-tube stationary boiler.

A horizontal return-tubular boiler and its setting is shown in perspective in Fig. 36. Part of the setting and boiler front *a* has been broken away in order to show the construction clearly. The tubes extend the whole length of the shell; their ends are expanded into holes in the boiler heads and beaded over. A smokebox *b* is formed at the front of the boiler by brickwork, the arch *c* separating the smokebox from the furnace. The connection to the chimney is made from

the top of the smokebox by a sheet-iron pipe, as a general rule; occasionally, a brick flue is formed on top of the boiler, the flue leading to the chimney. The boiler is supported on the brick walls by the brackets *d*, *d* riveted to the shell. These brackets usually rest on cast-iron plates let into the brickwork, rollers being interposed between the brackets and plates to allow the boiler to expand freely. A dome *e*, which increases the steam space, is usually provided, though this is sometimes left off. The walls are built and supported by buckstaves in practically the same manner as those previously described. Since this type of boiler is generally short, only one bridge is used. Firebrick is used for all parts of the wall exposed to the fire or heated gases. The fittings are not shown in the figure. The safety valve is placed on top of the dome, and the pressure gauge and gauge-cocks are placed on the front. The manhole is either in one of the heads or on top of the shell. The feedpipe may enter the front head, while the blow-off pipe *i* is placed at the bottom of the shell, at the rear end. Access is given to the rear end of the boiler through a clean-out door. The tubes are made accessible for cleaning out, etc. by large doors, as *f*, in the boiler front. The furnace *g* is placed under the front end of the boiler. The gases pass over the bridge *h*, along under the boiler into the chamber at the rear, then back through the tubes to the smokebox *b*, and thence to the chimney.

49. Locomotive, or Firebox, Boiler.—Next to the multitubular type, the firebox boiler is probably more used than any other type. It is used exclusively in railway service, and also largely as a stationary boiler. A large proportion of the small portable combined engines and boilers used for agricultural purposes are of this type. The general construction is shown in Fig. 37. The shell is composed of two differently shaped parts riveted together. The front part of the shell is cylindrical; the rear part is usually of a rectangular cross-section with vertical sides, or of a trapezoidal section with inclined sides; in either case the top is semicylindrical. The furnace *F* is a box of the same shape

as the rear end of the shell in which it is placed. There is a space left between the sides and the end of the furnace and the shell; this space is filled with water, as shown at A, A. A series of tubes extends from the front sheet of the furnace or firebox, to the front head of the shell. The shell is prolonged beyond the front head, forming a smokebox B, into which opens the stack C.

As shown in this figure, the **water legs** (as the spaces A, A are called) extend only as far as the grate, the ash-pit D being formed in the brick setting. In many boilers of this type the water legs extend to the bottom of the ash-pit, and sometimes there is a water space below the ash-pit; that is, the

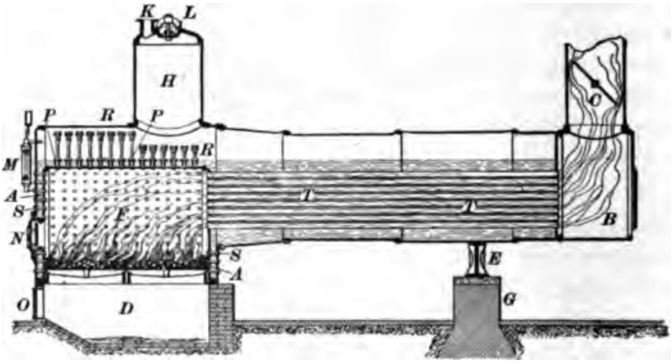


FIG. 37

furnace and ash-pit are entirely surrounded by water, and no brickwork setting is required.

The boiler is supported at the front end by the cast-iron cradle E resting on the masonry foundation G. The rear end is supported on a brick wall, which also forms the ash-pit. The boiler is usually provided with a dome H from which is led the main steam pipe, which is bolted on at K. In the figure, the dome is provided with a manhole L. The feedwater may be introduced at any convenient point in the shell. The pressure gauge, water glass, and gauge-cocks are attached to the column M, which is placed in communication with the interior of the shell. The furnace and ash-pit doors are shown at N and O, respectively. The safety valve

is usually attached to the dome. Since the flat sides of the furnace and shell are liable to bulge on account of the pressure, they must be braced or stayed. This is accomplished by the staybolts *S*, *S*. The flat top, or **crown sheet**, of the firebox is strengthened by a series of parallel girders *P*, *P*. As an additional security, the girders are sometimes attached to the shell by the sling stays *R*, *R*. The gases of combustion pass directly from the furnace through the tubes *T*, *T* to the smokebox *B*, and out of the stack *C*. In railway locomotives, a strong draft is obtained by allowing the exhaust steam to discharge through the smokestack. The escaping steam carries along the air and the escaping gases in the smokebox *B*, thereby drawing a new supply of gases through the tubes *T*, *T*, and a supply of air through the grate. The tubes of the locomotive boiler are about 12 feet long, 2 inches in diameter, and made of wrought iron or steel. The tubes of stationary and portable boilers of this type are generally of larger diameter, as there is less demand for great quantities of steam.

The locomotive type of stationary boiler is self-contained; that is, it requires no brickwork for flues or setting. This type of boiler is used by heating engineers chiefly for temporary heating or power purposes, because it obviates the expense of brick setting and delay incidental to the latter.

VERTICAL SHELL BOILERS

50. The vertical type of fire-tube shell boiler may be considered as a modification of a locomotive-type boiler placed on end, and, in common with that type, is self-contained. A common form of vertical boiler, shown in Fig. 38, consists of a vertical cylindrical shell, in the lower end of which is placed a firebox *F*. The lower rim of the firebox and the lower end of the shell are separated by a wrought-iron ring *k* to which both are riveted, the rivets going through both plates and ring. The shell and firebox are also stayed together by the staybolts *a*, *a*. The space between the two is filled with water, so that the firebox is

nearly surrounded by it. The boiler shell, and likewise the grate *E*, rest on a cast-iron base *D* that forms the ash-pit. A series of vertical tubes *t*, *t* extends from the top sheet of the firebox to the upper head of the shell. The tubes serve as stays, and strengthen the flat surfaces that they connect. The upper ends of the tubes open directly into the chimney,

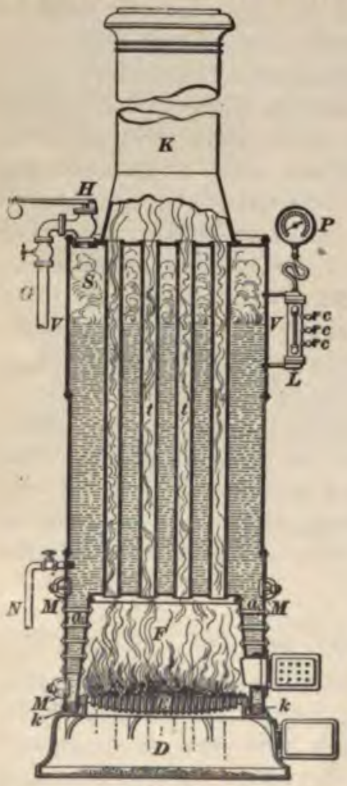


Fig. 38

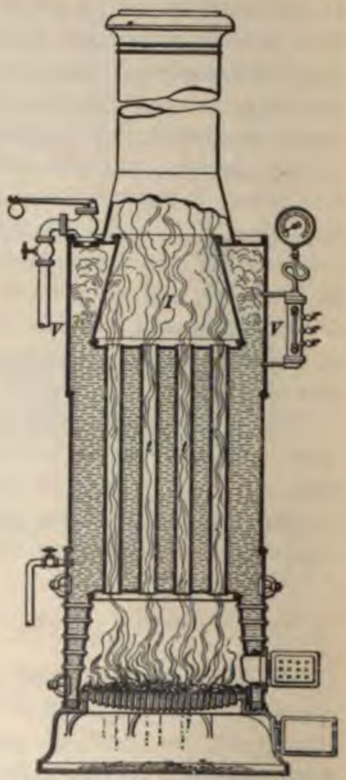


Fig. 39

or smokestack, *K*. The gases from the furnace thus pass directly through the tubes and out of the stack. The safety valve is shown at *H*, with the main steam pipe *G* leading from it. The pressure gauge *P* and gauge-cocks *c*, *c*, *c* are attached to a column *L*, which communicates in the usual manner with the interior of the shell. The construction of

this type of boiler does not generally permit the use of manholes, but handholes *M*, *M* are placed in convenient positions for cleaning out mud and sediment.

51. When the tubes extend through the upper head of the boiler, as shown in Fig. 38, their upper ends pass through the steam space *S* above the water-line *V*, *V*. This is looked on as a bad feature, since the tubes are liable to become overheated and thus collapse when the boiler is forced.

In the form of vertical boiler shown in Fig. 39, this danger is avoided. A chamber, or smokebox, *I* extends down from the upper head of the shell so that its bottom plate is always below the water-line. The upper ends of the tubes *t*, *t* are expanded into the lower plate of this chamber, and, therefore, the tubes are always surrounded by water from end to end. A vertical boiler constructed in this manner is said to have a *submerged head*. Aside from the submerged head, the construction of the boiler is similar to that shown in Fig. 38.

Vertical boilers are generally wasteful of fuel, and are perhaps more liable to explosion than any other type. They are, however, self-contained, require but little floor space, and are easy to construct and repair. For these reasons the vertical type of boiler is very popular for small installations with many steam users.

52. Boilers having the construction shown in Figs. 38 and 39 are very liable to throw sparks from the chimney, especially when the fire is forced. This makes their use dangerous in many localities. The Shapley vertical boiler has been designed to overcome this defect. It has drop flues passing down through the water space. The combination of the drop-tube flues and the smoke chamber at the base tends to prevent sparks from passing up the chimney, the sparks settling in the smoke chamber. This is an important fire preventive that should be considered in setting boilers in back-yard sheds or other dangerous places.

WATER-TUBE POWER BOILERS

STRAIGHT-TUBE BOILERS

53. Babcock & Wilcox Boiler.—Water-tube boilers may be divided into straight-tube and bent-tube boilers. One of the best known straight-tube water-tube boilers is the Babcock & Wilcox boiler illustrated in Fig. 40. It consists essentially of a main horizontal drum *B* and of a series of inclined tubes *T*, *T*. Only a single vertical row of tubes is shown in the figure, but it will be understood that each nest of tubes is composed of several vertical rows. There are usually 7 or 8 of these vertical rows to each horizontal

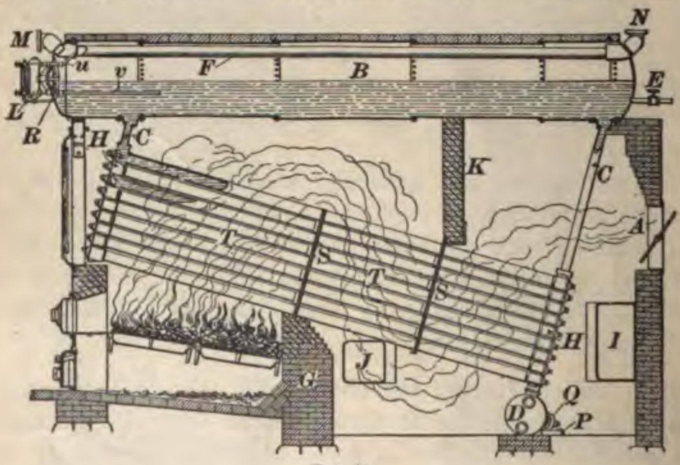


FIG. 40

drum. The front ends of the tubes of a vertical row are all expanded into a hollow iron or steel fitting *H*, called a **header**. The rear ends are expanded into a similar header, and the front and rear headers are placed in communication with the drum by tubes, or **risers**, *C*, *C*. In front of each tube a handhole is placed in the header for the purpose of cleaning, inspecting, or removing the tubes.

The method of supporting the boiler is not shown in the figure. The usual method is to hang the boiler from

wrought-iron girders resting on vertical iron columns. The brickwork setting is not depended on as a means of support. This make of boiler, in common with most others of the water-tube type, requires a brickwork setting to properly confine the furnace gases.

The furnace is of the usual form, and is placed under the front end of the nest of tubes. The bridge wall *G* is built up to the bottom row of tubes; another firebrick wall *K* is built between the top row of tubes and the drum. These walls and the baffle plates *S*, *S* force the hot furnace gases to follow a zigzag path back and forth between the tubes. The gases finally pass through the opening *A*, in the rear of the wall, into the chimney flue. The feedwater is introduced through the feedpipe *E*. The steam is collected in the dry pipe *F*, which terminates in the nozzles *M* and *N*, to one of which is attached the main steam pipe, and to the other the safety valve. The pressure gauge, cocks, etc. are attached to the column *L*, which communicates with the interior of the shell by the small pipes *u* and *v*, the former of which extends into the dry pipe, the latter into the water. At the bottom of the rear row of headers is placed the mud-drum *D*. Since this drum is the lowest point of the water space, most of the sediment naturally collects there. This sediment may be blown out from time to time through the blow-off pipe *P*. The drum *D* is provided with a handhole *Q*, and a manhole *R* is placed in the front head of the drum *B*. The heads of the drums are of hemispherical form, and therefore do not require bracing. Access may be had to the space within the walls through the doors *I* and *J*. The circulation of water takes place as follows: The feedwater is introduced into the rear of the steam drum; the furnace being under the higher end of the tubes, the water in that end expands on being heated, and is also partly changed to steam; hence, a column of mingled water and steam rises through the front headers to the front end of the drum *B*, where the steam escapes from the surface of the water. In the meantime, the feedwater fed into the rear of the drum descends to the rear headers through the long tubes *C* to take the

place of the water that has risen in front. Thus, there is a continuous circulation in one direction, sweeping the steam to the surface as fast as it is formed, and supplying its place with cooler water. Most of the sediment sinks to the mud-drum *D*, from which it is blown out from time to time.

54. Root Water-Tube Boiler.—The construction of the Root water-tube boiler, shown in Figs. 41 and 42, is similar to that of the Babcock & Wilcox boiler. Fig. 41 gives a longitudinal section, and Fig. 42 an end view with

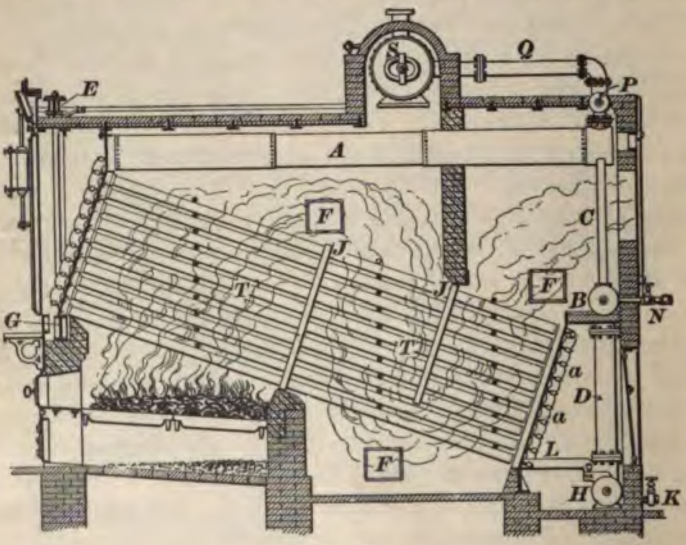


FIG. 41

the brickwork removed to show the various drums and connections. The construction of this boiler is very similar to that of the one just described. There is a nest of inclined tubes, the ends of which are expanded into headers. The headers are placed in communication by the **U**-shaped return bends *a*, *a*. A continuous channel is therefore provided for the circulation of the water through the headers. There is a horizontal overhead drum *A* for each vertical section of tubes. These drums *A*, *A* are placed in communication with the transverse drum *B* by the tubes *C*, *C*. The drum *B* is in

turn connected with the lower drum *H* by the two large water legs *D*, *D*. Finally, the drum *H* communicates with the rear headers through the tubes *L*, *L*. There is thus an open circuit through the tubes *T*, drum *A*, tubes *C*, drum *B*, water legs *D*, drum *H*, and tubes *L*. The water-line is at about the middle of the drums *A*, *A*, and the steam rising from the surface of the water first passes into the drum *P*, and then into the main steam drum *S* through the pipes *Q*, *Q*. The main steam pipe, the safety valve, and other fittings may be attached to the drum *S* at the nozzles *U*, *V*, and *W*. The feedwater is introduced into the drum *B* through the feedpipe *N*. The circulation takes place in the same manner as in the Babcock & Wilcox boiler. The drum *H* acts as the mud-drum, being at the lowest point of the water circuit. The sediment may be blown out through the pipe *K*. Access may be had to the interior of the setting through the doors *F*, *F*. The steam drum is provided with a manhole. The rear end of the boiler is supported by the brickwork foundation; the front end is supported by a beam *G* hung from the I beam *E*. The arrangement of the bridge and baffle plates *J*, *J* and the course of the heated gases are precisely the same as in the Babcock & Wilcox boiler. The points of superiority claimed by the makers of the Root boiler are: the flexible construction of the headers, allowing for expansion and contraction; the use of numerous small overhead drums instead of one or more large ones; the introduction of the feedwater into a separate drum; the admission of the circulating water directly into the lower tubes, thus protecting them from the intense heat of the furnace.

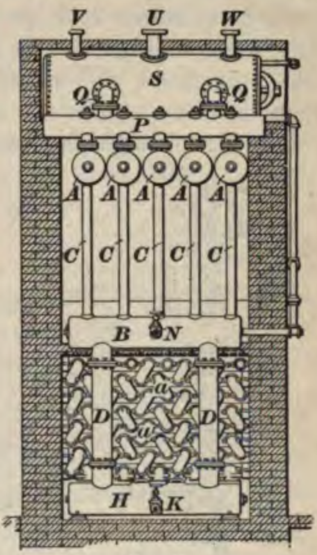


FIG. 42

There are several other makes of similar water-tube boilers, varying only in detail from the two just described. They all consist essentially of a bank of 4-inch tubes, inclined at an angle of about 15 degrees, connected by headers and tubes with a horizontal steam drum, the tubes, headers, and drums forming a closed circuit through which the water circulates.

55. Heine Boiler.—A boiler differing in many respects from those shown in Figs. 40, 41, and 42 is the Heine boiler, illustrated in Fig. 43. It consists of a large main drum *A*, which is above and parallel with the nest of tubes *T*, *T*. Both drum and tubes are inclined at an angle with the horizontal that brings the water level to about one-third the

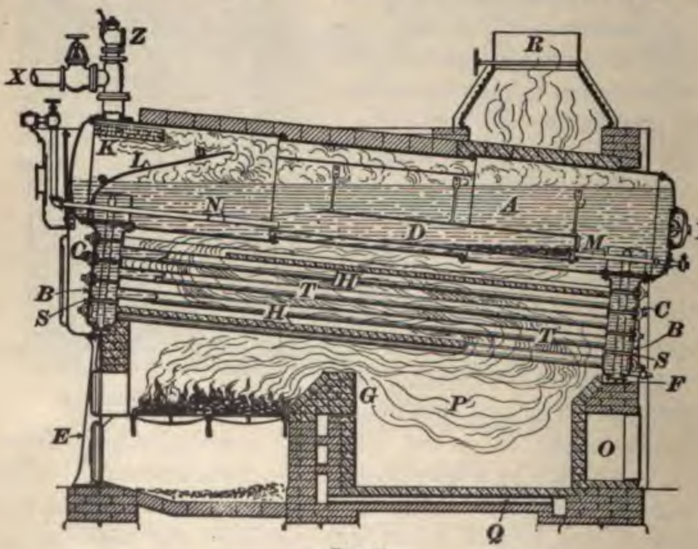


FIG. 43

height of the drum in front and about two-thirds the height in the rear. The ends of the tubes are expanded into the large wrought-iron water legs *B*, *B*. These legs are flanged and riveted to the shell, which is cut out for about one-fourth of its circumference to receive them, the opening being from 60 to 90 per cent. of the cross-sectional area of the tubes. The drum heads are of a hemispherical form, and

therefore do not need bracing. The water legs form the natural support of the boiler, the front water leg being placed on a pair of cast-iron columns E that form part of the boiler front, while the rear water leg rests on rollers, shown at F, which may move freely on a cast-iron plate bedded in the rear wall. These rollers allow the boiler to expand freely when heated. The boiler is enclosed by a brickwork setting in the usual manner. The bridge G, made largely of firebrick, is hollow, and has openings in the rear to allow air to pass into the chamber P and mix with the furnace gases. This air is drawn from the outside through the channel Q in the side wall, and it is, of course, heated in passing through the bridge. In the rear wall is the arched opening O, which is closed by a door and further protected by a thin wall of firebrick. When it is necessary to enter the chamber P, the wall at O may be removed, and afterwards replaced. The feedwater is brought in through the feedpipe N, which passes through the front head. As the water enters, it flows into the mud-drum D, which is suspended in the main drum below the water-line, and is thus completely submerged in the hottest water in the boiler. This high temperature is useful in precipitating the impurities contained in the feedwater, which settle in the mud-drum D, and may then be blown out through the blow-off pipe M. Layers of firebrick H, H are laid at intervals along the rows of tubes, and act as baffle plates, forcing the furnace gases to pass back and forth over the tubes. The gases finally escape through the chimney R placed above the rear end of the boiler. To protect the steam space of the drum from the action of the hot gases, the drum in the vicinity of the chimney is protected by firebrick, as shown in the figure. The steam is collected and freed from water by the perforated dry pipe K. The main steam pipe with its stop-valve is shown at X, and the safety valve at Z. In order to prevent a combined spray of mixed water and steam from spurting up from the front header and entering the dry pipe, a deflecting plate L is placed in the front end of the drum. A manhole Y is placed in the rear head of the drum. The flat sides of the

water legs are stayed together by the staybolts *S*, *S*, which are made hollow to give access to the outside of the tubes. In front of each tube a handhole *C* is placed to give access to the interior of the tubes.

Where a battery of several of these boilers is used, an additional steam drum is placed above and at right angles to the drums *A*.

BENT-TUBE AND SECTIONAL POWER BOILERS

56. Stirling Boiler.—One of the best-known bent-tube types of stationary boilers is the Stirling water-tube boiler

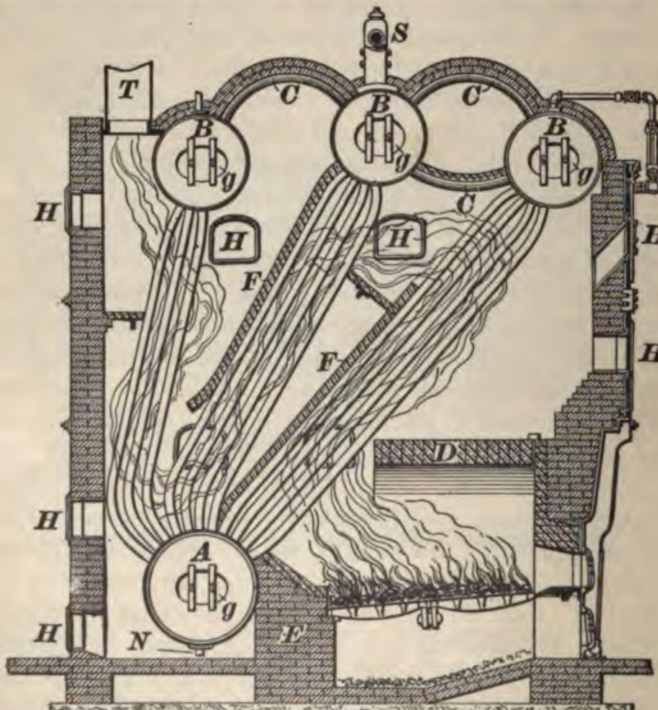


FIG. 44

shown in Fig. 44. It is quite a departure from the regular type of water-tube boilers. It consists of a lower drum *A* connected with three upper drums *B*, *B*, *B* by three sets of

nearly vertical tubes. These upper drums are connected by the curved tubes *C*, *C*, *C*. The curved forms of the different sets of tubes allow the different parts of the boiler to expand and contract freely without strain. The boiler is enclosed, as shown, in a brickwork sètting, which is provided with various holes *H*, *H*, so that the interior may be inspected or repaired. The boiler is suspended from a framework of wrought-iron girders, not shown in the figure. The bridge *E* is lined with firebrick, and is built in contact with the lower drum *A* and the front nest of vertical tubes. An arch *D* is built above the furnace, and this, in connection with the bafflers *F*, *F*, directs the course of the heated gases, causing them to pass up and down between the tubes. The arch and bafflers are made of firebrick. The cold feedwater enters the rear upper drum and descends through the rear nest of tubes to the drum *A*, which acts as a mud-drum, and collects the sediment brought in by the water. A blow-off pipe *N* permits the removal of the sediment. The steam collects in the upper drums *B*, *B*. The steam pipe and safety valve *S* are attached to the middle drum. The chimney *T* is located behind the rear upper drum. The water column *L*, with its fittings, is placed in communication with the front upper drum. All the drums are provided with large manholes *g*. The boiler is made with a cast-iron front.

The following advantages are claimed for the Stirling boiler: (1) The vertical position of the tubes prevents the collection of sediment, and at the same time encourages the rapid rise and separation of the steam as soon as it is formed; (2) the boiler is very simple and easy to construct; there are no flat surfaces to be stayed, and there is little or no machine work required in its manufacture; (3) it is very accessible for cleaning or repairs; any part of the drums may be inspected by removing the four manhole plates *g*, *g*.

57. Harrison Safety Boiler.—While the boiler shown in Fig. 45 is not a water-tube boiler, the fact of its following the same general method of construction to insure safety, which is the subdivision of the contained water into small

bodies, warrants its description here. The Harrison safety boiler is composed of hollow cast-iron or steel sections *A, A*, called **units,** which are accurately faced and bolted together. Each section is composed of two or more approximately spherical vessels, and the sections are bolted together in a zigzag manner, as shown in the figure, so as to form a solid slab. Each bolt runs from top to bottom through all the units, as shown at *C*. There are several of these vertical slabs of sections suspended side by side from the girders *B, B*.

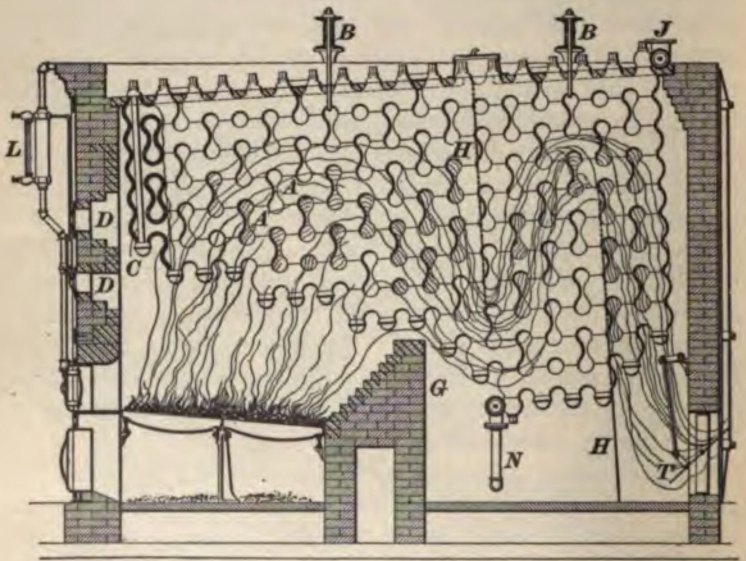


FIG. 45

The boiler is enclosed by brickwork setting, which is lined with firebrick. The top of the boiler is likewise covered with firebrick to prevent radiation. The wall is pierced with the openings *D, D* for the purpose of inspecting the interior. The bridge *G* and bafflers *H, H* direct the hot gases back and forth between the sections.

The feedwater enters the boiler at its lowest point through the feedpipe *N*. The steam pipe is bolted on at the flange *J*. The water column *L*, placed in front at the height of the

water level, is connected by pipes with the steam and water spaces, respectively.

The chimney flue is placed at the rear near the floor; the draft is regulated by the damper *T*.

The boiler is essentially a safety boiler. If the steam pressure becomes excessive, the bolts *C* will elongate a little and allow steam to escape through the joints.

BOILER FITTINGS

STEAM-GENERATOR FITTINGS

STEAM AND WATER RESERVOIRS

STEAM DOMES

1. A **steam dome** is a cylindrical vessel riveted to the shell of horizontal power boilers for the purpose of increasing the steam space, and also for the purpose of drying the steam, the supposition being that the steam will be dried on account of its being farther removed from the water. The hole cut in the shell to give communication between the boiler and dome should be made only large enough to allow a man to pass through, since a large hole materially weakens the shell. The edge of the plate around the hole should be reenforced by a wrought-iron ring riveted to it. Small holes should be drilled through the shell plate at each side of the boiler inside of the dome, where a depression is formed, to allow the water that accumulates there to drain back into the boiler. The dome flange fitting the boiler shell is called the **saddle**, and should be double-riveted to the shell. Steam domes usually have a diameter equal to half the diameter of the boiler, and a height equal to about nine-sixteenths the diameter of the boiler, the proportions given being the average in modern practice.

2. The top of the steam dome is closed by the **dome head**, which formerly was made of cast iron. Owing to the high pressures now carried, the use of cast-iron heads

for high-pressure boilers has been almost entirely abandoned, by reason of the treacherous nature of the material. In the best modern practice, flanged and crowned steel heads are used, the head being crowned to a radius sufficient to make it stiff enough to withstand the pressure without additional bracing. When flanged flat steel heads are used, they must be well braced by diagonal braces.

STEAM DRUMS

3. Boilers are often fitted with a **steam drum** instead of a dome. The steam drum is simply a cylindrical vessel connected to the shell. When several boilers are set so as to form a battery, they are often connected to a drum common to all boilers. When each boiler has its own furnace, there should be a stop-valve between each boiler and the drum to allow the boiler to be taken out of service when required. When the boilers in battery have a furnace common to all, no stop-valve should ever be placed in the pipe connections between each boiler and the drum. Where boilers are in battery with separate furnaces, each boiler must have its own safety valve, which should always be so fitted that it cannot be cut off from the boiler under any circumstances.

Longitudinal steam drums are sometimes attached to the boiler by two nozzles. This practice is objectionable, however, since with an unequal expansion of the boiler and drum, which is quite likely to occur, the joints of the nozzles will become leaky, owing to the strains to which they are subjected. It is now the rule in good work to use one nozzle only. When the steam drum is used for a single boiler, its diameter averages half the diameter of the boiler, and its length the diameter of the boiler. Where one steam drum is common to several boilers, its diameter averages half the diameter of the boiler, and its length the horizontal outside to outside measurement over the several boiler shells. Steam drums require just as rigid inspection as the boiler itself.

MUD-DRUMS

4. A **mud-drum** is a cylindrical vessel occasionally attached to a power boiler for the purpose of providing a quiet place for the collection of mud and sediment in mechanical suspension in the feedwater, which is then introduced into the mud-drum. It is located underneath the boiler and at the rear end, being connected to the boiler by a suitable nozzle, usually of cast iron. Where several boilers are set in battery, they are sometimes connected to a common mud-drum. This practice is permissible when the whole battery is used at once. When so fitted, none of the boilers can be temporarily taken out of service unless each nozzle is provided with a stop-valve. Owing to the difficulty of protecting the valve from the fire, this is rarely done. This consideration limits the use of a common mud-drum to cases where all the boilers are worked together. When a mud-drum is fitted, the blow-off should be attached to it and the sediment collected in the drum frequently blown out.

BOILER SAFETY DEVICES

SAFETY VALVES

5. The **safety valve** is a device attached to the boiler to prevent the steam pressure from rising above a certain point. It consists simply of a plate, or disk, fitting over a hole in the boiler shell, and held to its place in one of three ways: (1) By a dead weight; (2) by a weight on a lever; (3) by a spring.

The weight or spring is so adjusted that when the steam reaches the desired pressure the disk is raised from its seat, and the surplus steam escapes through the opening in the shell.

6. The **dead-weight safety valve**, in modern practice, is used only for low-pressure boilers. It has the advantage of simplicity and compactness, and cannot readily be tampered with. The construction of a modern dead-weight safety

valve is shown in Fig. 1. It consists of a shell *a* screwed in the top of the boiler, the upper part forming the valve seat.

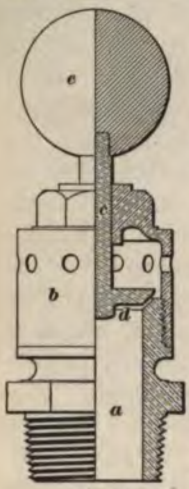


FIG. 1

The cap *b*, which is perforated to allow the steam to escape, forms the guide for the valve stem *c*. The valve disk *d* closes the opening. The dead weight resisting the steam pressure consists of the ball *e* and the weight of the valve and stem, and this dead weight is such that the valve will raise off its seat, as shown in the illustration, when the steam pressure exceeds 10 pounds per square inch. On special order, valves of the form shown can be obtained weighted for other pressures than 10 pounds.

7. A **lever safety valve** is shown in Fig. 2. The steam from the boiler enters at *S* and escapes at *R* when the steam pressure is sufficient to raise the valve *V* off its seat. The valve is held to its seat by the weight *W* hung from the lever *L*. The load on the valve is changed

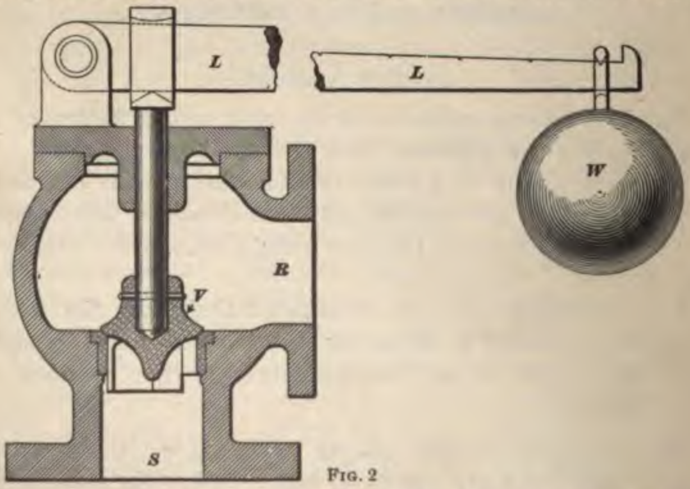


FIG. 2

by shifting the weight along the lever. Notches are cut into the lever, and figures stamped below the notches indicate the

blowing-off pressure, in pounds per square inch, when the weight is hung in the notch above the figures.

8. A **spring-loaded safety valve** is shown in Fig. 3. The valve *a* is held down by a helical spring *b*, the tension of which can be altered by the screw-cap *c*. When the boiler pressure rises sufficiently to lift the valve, the steam escapes into the chamber *d* and thence through a pipe attached at *e* to the atmosphere. Owing to the abrupt manner in which the valve opens and closes, it is often called a **pop safety valve.**

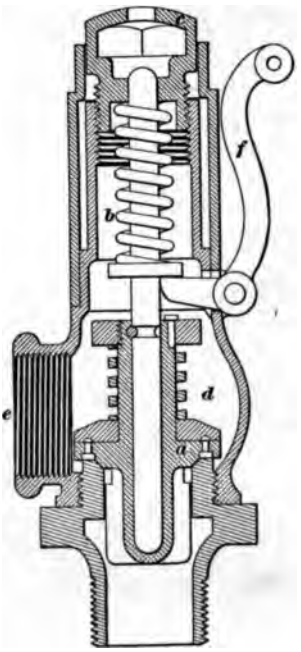


FIG. 3

Spring-loaded safety valves are adjusted to the blowing-off pressure desired by getting up a steam pressure in the boiler to which they are attached. When the steam gauge indicates the desired blowing-off pressure, the tension of the spring is decreased until the valve opens.

Dead-weight and lever safety valves do not open fully until the pressure in the boiler exceeds, by several pounds, the pressure the valve is set for. Pop valves, however, operate promptly, and close just as promptly, and for this reason are deservedly preferred. Another reason for preferring the spring valve to all other kinds is the facility with which it can be enclosed in a case and locked up, so as to prevent all changing or tampering by unauthorized persons.

9. The area of a safety valve should be large enough to discharge the steam as rapidly as the boiler can generate it. The size of the valve relative to the size of boiler and working pressure is prescribed by law in many localities, and must be made to conform to the law wherever such law is in

existence. In localities having no law governing this matter, the size of the safety valve may be calculated by the rule prescribed by the Bureau of Steam Boiler Inspection of the city of Philadelphia, Pennsylvania, which rule is also used by the Hartford Steam Boiler Inspection and Insurance Company. Many other rules differing widely in their results are in use, but the rule here given has stood the test of time, and is unqualifiedly indorsed for boilers working under natural draft.

Rule.—*To find the area of a safety valve, in square inches, multiply the grate surface of the boiler, in square feet, by 22.5. Divide the product by the sum of the gauge pressure it is proposed to carry, in pounds per square inch, and 8.62.*

Or
$$A = \frac{22.5\,G}{P + 8.62}$$

where A = area of safety valve, in square inches;
G = grate surface, in square feet;
P = gauge pressure, in pounds per square inch.

Example.—What area of safety valve is required for a boiler having a grate surface of 24 square feet and that is to carry a pressure of 70 pounds per square inch?

Solution.—Applying the rule just given,

$$A = \frac{24 \times 22.5}{70 + 8.62} = 6.87 \text{ sq. in.} \quad \text{Ans.}$$

10. It is common practice in some localities to connect a pipe to the blow-off side of the safety valve for the purpose of carrying the steam blown off to the outside of the building. Such an escape pipe, while harmless enough when of sufficient area and kept well drained, may become a source of danger if no provision is made for draining it constantly. Instances are not rare where, owing to the absence of a drain pipe, the escape pipe has become filled with water, thus adding greatly to the external force on the valve and rendering it inoperative for the blow-off pressure for which it was set. When an escape pipe is used at all, it should not be of smaller diameter than the valve, and should have a drain pipe of ample size at its lowest point.

No cock or valve should under any circumstances be placed in this drain pipe.

11. Safety valves should in all cases be attached to the boiler in such a manner that it is an absolute impossibility to shut off connection between the boiler and its safety valve. They should be fitted with a chain, leading to some convenient spot, for raising the valve off its seat. Spring-loaded safety valves usually have a bell-crank lever, as *f*, Fig. 3, to which the chain is attached.

STEAM GAUGE

12. The **steam gauge** indicates the pressure of the steam contained in the boiler. The most common form is the *Bourdon pressure gauge*, the distinguishing feature of which is a bent elliptical tube tending to straighten out under an internal pressure. Bourdon pressure gauges are made in various ways by the different manufacturers; a very common design is shown in Fig. 4. It consists of a tube *a*, of elliptical cross-section, that is filled with water and connected at *b* with a pipe leading to the boiler. The two ends, as *c*, are closed and are attached to a link *d*, which is, in turn, connected with a quadrant *e*; this quadrant gears with a pinion *f* on the axis of the index pointer *g*. When the water contained in the elliptical tube is subjected to pressure, the tube tends to take a circular form, and, as a whole,

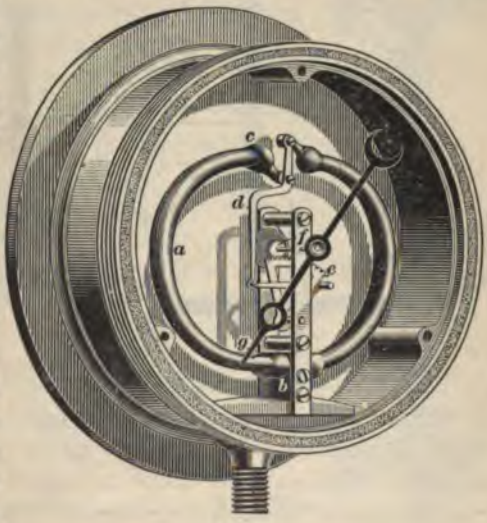


FIG. 4

straightens out, throwing out the free ends a distance proportional to the pressure. The movement of the free ends is transmitted to the pointer by the link, rack, and pinion, and the pressure is thus recorded on a graduated dial in front, which has been removed in order to show the mechanism.

Pressure gauges for indicating steam pressure are invariably graduated to indicate pressure, in pounds per square inch, wherever the English system of weights and measures is used, and show how much the pressure has been increased above the atmospheric pressure.

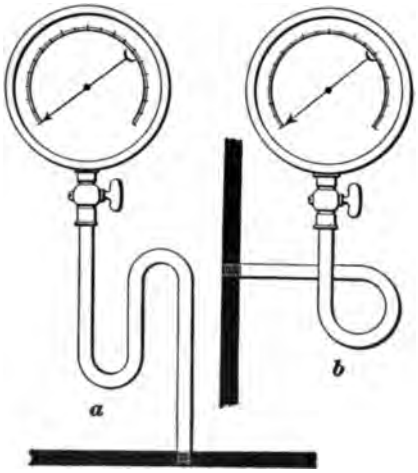


FIG. 5

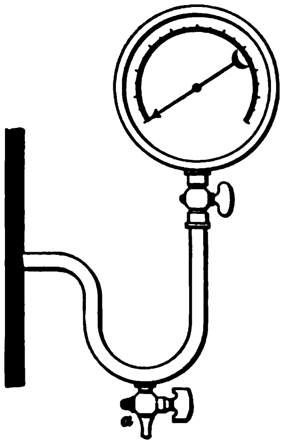


FIG. 6

13. The gauge should be connected to the boiler in such a manner that it will neither be injured by heat nor indicate a wrong pressure. To prevent injury from heat, a so-called siphon, which may be made as shown at *a* or *b*, Fig. 5, is usually placed between the gauge and the boiler. This siphon in a short time becomes filled with condensed steam that protects the spring of the gauge from the injury the hot steam would cause. Care should be taken not to locate the steam-gauge pipe near the main steam outlet of the boiler, since this may cause the gauge to indicate a lower pressure than

really exists. In locating the steam gauge, care must also be taken not to run the connecting pipe in such a manner that the accumulation of water in it will cause an extra pressure to be shown.

The gauge connections shown in Fig. 5 cannot be drained without disconnecting them. To obviate this drawback, the gauge may be connected as shown in Fig. 6, placing a petcock *a* at the lowest point.

GLASS WATER GAUGES

14. The **gauge glass** is a glass tube whose lower end communicates with the water space of the boiler and whose upper end is in communication with the steam space. Hence, the level of the water in the gauge should be the same as in the boiler.

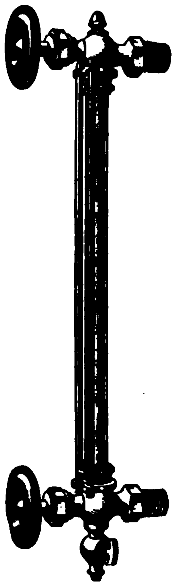


FIG. 7

Fig. 7 shows a common form of gauge-glass connection. The lower fitting connects with the water space, and the upper fitting with the steam space, of the boiler. A drip cock is placed at the lower end of the glass for the purpose of draining it. Two brass rods tend to protect the gauge glass against accidental breakage. The fittings may be screwed directly into the boiler. The gauge should be so located that the water will show in the middle of the gauge glass when at its proper level in the boiler. Both fittings have compression valves, by means of which communication with the boiler can be shut off in case the gauge glass breaks.

15. Owing to the danger of scalding the hands and face that is incurred by shutting off the valves, and also to prevent the loss of steam and water, it is desirable for high-pressure work to have water gauges that will automatically shut off communication with the boiler whenever the gauge glass breaks. There are many designs of such water gauges on

the market, one of which, typical of the others, is shown in Fig. 8. A ball is placed within the shank of each fitting, as shown, and is prevented from falling out by a brass pin. Should the gauge glass break, the outrushing steam and water carry the balls forwards and thus close the openings leading to the gauge glass. While the balls may not shut off the steam and water entirely, they will check the outflow sufficiently to permit the valves to be closed without danger.

16. To obviate the danger of scalding the hands, the "*P. B. H.*" *quick-closing water gauge* has been placed on

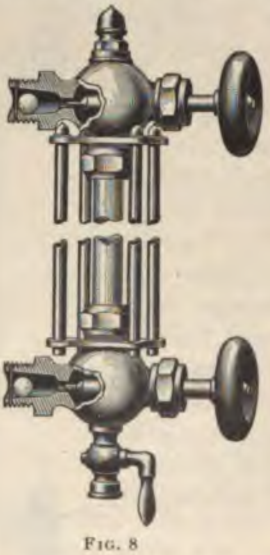


FIG. 8

FIG. 9

the market. In this, as shown in Fig. 9, a two-armed lever is placed on each valve stem. Chains are led from the ends of the levers to some safe point, and the valves are opened and closed by pulling the chains.

17. Glass water gauges connected directly to the boiler are open to the objection that the violent ebullition at the

surface of the water will cause them to indicate a wrong water level. To overcome this objection, they are frequently placed on a separate fitting known as a *water column*, which consists of a large hollow tube with its ends connecting with the steam and water spaces of the boiler far enough above and below the water level to be out of reach of the violent ebullition of the surface of the water.

GAUGE-COCKS

18. A **gauge-cock** is a simple cock or valve attached either directly to the boiler or, preferably, to a water column for the purpose of testing the level of the water in the boiler. Three gauge-cocks are generally employed. The lowest is placed at the lowest level that the water may safely attain, and the uppermost at the highest desirable level. The third cock is placed midway between the other two. On opening a cock above the water level, steam will issue forth, and on opening one below the water level, water will appear. Hence, the level may be easily located by opening the cocks in succession.

19. The gauge-cocks most commonly used are of the *compression* type. Such a cock, with a wooden hand wheel, is shown in Fig. 10. It consists of a brass body *a* having a threaded shank for attaching it to the boiler or water column. The seat within the body is closed by the end of the threaded valve stem *b*. The steam or water issues from the nozzle *c* when the cock is open.

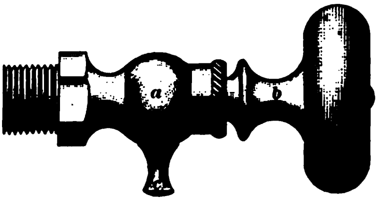


Fig. 10

Compression gauge-cocks can be obtained with a lever handle in the form of a crank. Such cocks can be operated from a distance by means of a rod. In some designs the valve is held to its seat by a strong spring, which automatically closes the valve the moment the hand releases it.

20. A weighted gauge-cock, known to the trade as a *Register pattern cock*, is shown in Fig. 11. It consists of a body *a* having a threaded shank for attaching it to the boiler or water column. The weight *b* is pivoted at *c* to the body, and when down presses a strip *d* of soft-rubber packing against the face of the opening at *e*. The cock is opened by lifting the weight slightly, and the issuing steam or water is deflected downwards by the curved end wall of the slot. In order to show the construction clearly, the weight is shown raised to the full limit. The strip of soft-rubber packing is simply pushed through two opposite slots. It must be renewed quite frequently, as it rots under the high temperature to which it is subjected.

FIG. 11

WATER COLUMNS

21. A common form of **water column** is shown in Fig. 12. It consists of a hexagonal cast-iron stand pipe *a* tapped on top and bottom for pipe connections to the boiler. Tapped bosses are provided, which receive the threaded shanks of the gauge-glass fittings *b, b* and the gauge-cocks *c, c, c*. Each maker has his own style of stand pipe, the different makes varying chiefly in the ornamentation. The steam gauge is frequently mounted on top of the water column.

22. The connection to the boiler should be made with a **T** on top and a cross on the bottom, as shown, plugging up the unused openings with brass plugs. If the connections are made in this manner, they can be cleaned with a rod when the plugs are unscrewed. A drain pipe *d* with a valve in it, and leading to the ash-pit, should always be provided for the stand pipe, and should be frequently used for blowing out sediment collecting in the stand pipe. For low-pressure boilers, no valves need be placed in the pipes

leading to the steam and water spaces of the boiler; for high-pressure boilers, however, valves should always be provided. These valves are used in blowing out the stand pipe and connections. Closing the valve in the upper pipe and opening the valve in the drain pipe blows out the lower pipe; closing the valve in the lower pipe and opening the valve in the drain pipe blows out the upper pipe and the stand pipe.

23. Fig. 13 illustrates how a steam gauge N may be attached to the water column by

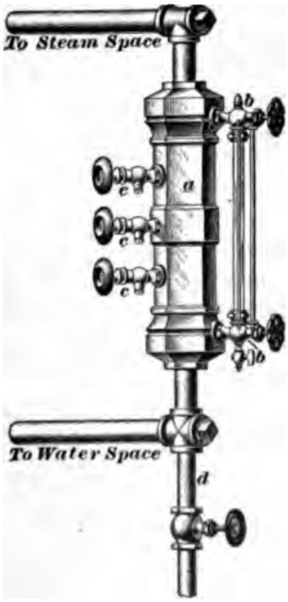


FIG. 12

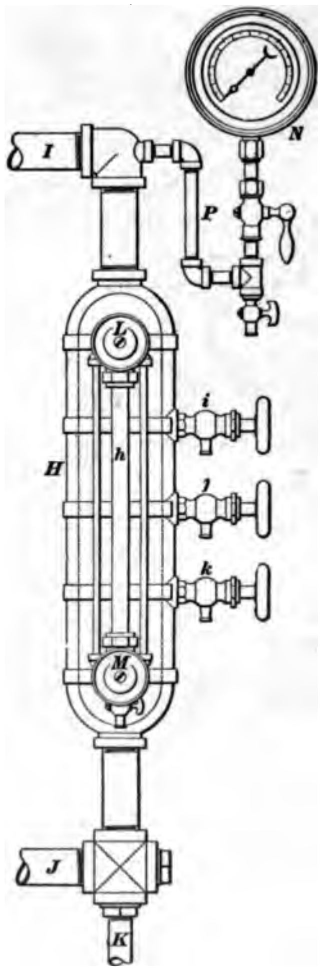


FIG. 13

means of a siphon P made from ordinary brass pipes and fittings. The stand pipe H carries on one side the upper fitting L and lower fitting M for the gauge glass h, and at

right angles to this gauge the three gauge-cocks *i*, *j*, and *k*. The pipe *I* leads to the steam space of the boiler and the pipe *J* to the water space. A drain pipe *K* is attached to the cross shown. The arrangement illustrated is recommended by the Hartford Steam Boiler Inspection and Insurance Company.

LOW- AND HIGH-WATER ALARMS

24. In large heating and power plants a device is often attached to the boiler that will give an audible warning, usually by blowing a whistle, of a shortage or surplus of water. Devices that will indicate a shortage of water are called **low-water alarms**; those that indicate both a shortage or a surplus of water are called **high- and low-water alarms.**

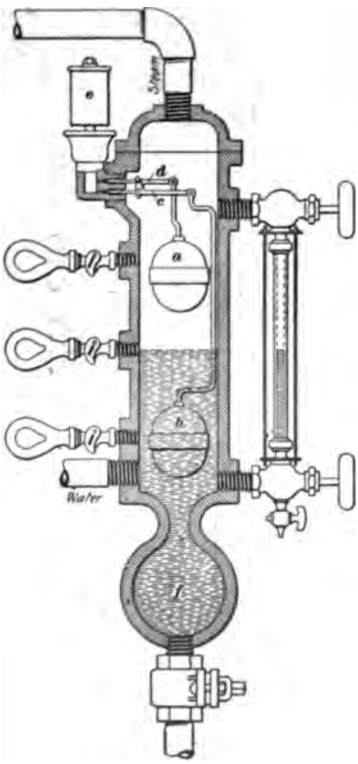


FIG. 14

25. In purely low-water alarms, the whistle may be sounded by the melting of a fusible plug, which, through the falling of the water level in a separate chamber outside of the boiler, is brought in contact with the steam. Fusible-plug alarms are cheap and easily applied; they are rather unreliable, however, because of their liability to become incrusted with scale. Alarms depending on the melting of a fusible plug should never be applied to low-pressure boilers, since the temperature of the steam in them is insufficient to quickly melt the plug.

26. Most low-water alarms employ a float operating a valve leading to a steam whistle, the float being buoyed up by the water. Their construction is so similar to that of high-and-low water alarms that illustrations of them would only be duplications of the latter.

27. The Reliance high-and-low water alarm is shown in Fig. 14. The device consists of two hollow floats *a*, *b* suspended from the bell-cranks *c*, *d*. To the short arm of each bell-crank is attached the valve stem of a small valve, there being one valve for each float. These valves serve to put the steam space of the water column in communication with the alarm whistle *e*. In this particular design, a sediment chamber *f* is formed at the bottom of the column and collects all foreign matter that settles from the water. The water-column drain is connected to the settling chamber. When the water is at its proper level, the float *b* is surrounded by water and, being hollow, is pressed upwards; this keeps the upper whistle valve closed. Let the water become low in the column so as to begin to uncover the float. Then, the upward pressure due to the buoyant effect of the water gradually diminishes and finally will become so small that the float will descend, thus opening the upper whistle valve and sounding the alarm. The high-water alarm float *a* keeps the lower whistle valve closed by the weight of the float. When the water rises, the float is carried upwards, the lower whistle valve is opened, and the alarm sounded.

28. Low-water alarms depending on the difference in expansion of different metals for actuating a whistle valve or electric bell have been used occasionally and are on the market; they have not found much favor, however, chiefly on account of being too delicate.

STEAM WHISTLE

29. While the steam whistle is not essentially a boiler safety device, yet the fact of its being used in connection with low- and high-water alarms, besides being used for signaling purposes, warrants a description of its principle of

action in connection with the subject of safety devices. Two of the most common constructions, as used for signaling, are shown in Figs. 15 and 16. The bell, as shown in Fig. 15, is a hollow cylinder closed at the top and open at the bottom, and is held in position by a stud that passes through the center and is secured at the upper end by means of a screw and jam nut. The hollow base has a narrow circular orifice that communicates with the steam pipe and valve. As the steam rushes out of the orifice in an upward direction, toward the mouth of the bell, it slightly compresses the air contained in the bell. The air being elastic will not retain a fixed or stationary position, but will slightly spring back toward the

FIG. 15

FIG. 16

inrushing steam, where it is again forced back in a compressed state, causing a vibration of the air and steam. These vibrations continue so long as steam is permitted to flow, and are communicated to the surrounding atmosphere, thus producing sound.

The tone may be changed to a higher pitch by lowering, or to a lower pitch by raising, the bell. This may be done by loosening the jam nut and turning the bell up or down, after which the nut should be again tightened.

Whistles are also constructed to produce two or more tones of different pitch simultaneously by dividing the bell into

two or more cell-like parts, as shown in Fig. 16. Each apartment produces a different tone, and when these tones chord perfectly, the effect is quite pleasing.

30. In manufacturing establishments, the whistle for signaling is usually located on the roof; that is, at a considerable distance above the boiler. In order to prevent this long pipe becoming filled with water, it is advisable to fit a small drain pipe and valve directly above the stop-valve in the whistle pipe, which is placed close to the boiler. At night, the steam may be shut off from the whistle and the drain valve opened.

FUSIBLE PLUGS

31. A **fusible plug** is a device that, by the melting of its filling when exposed to an undue temperature, gives warning of low water in the boiler. In many places, fusible plugs are required by law to be attached to all high-pressure boilers, whether used for power or heating purposes. While they are sometimes fitted to low-pressure boilers, they are worthless where so used, since the filling of the ordinary commercial plugs does not melt at the temperature corresponding to the low steam pressure carried.

32. The ordinary fusible plug in common use is shown in section in Fig. 17. It consists of a brass or iron shell threaded on the outside with a standard pipe thread. The plug has a conical filling, the larger end of the filling receiving the steam pressure. The conical form of the filling prevents its being blown out by the pressure of the steam.

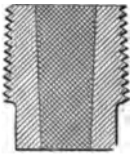


Fig. 17

The plug filling is either an alloy of lead, tin, and bismuth, or pure Banca tin. As long as the plug is well covered with water, it is kept from melting by the water, but should the water sink low enough to uncover the plug, it quickly melts and allows the steam and water to rush into the furnace, thus giving warning of low water by the noise produced.

33. A form of plug especially adapted to internally fired boilers of the locomotive type is shown in Fig. 18. The plug *a* is screwed into the crown sheet *b*, and the fusible cap *c* is laid on top of it and kept in place by the nut *d*. A very thin copper cup *e* is placed over the top of the cap *c* to protect it from any chemical action of the water. The top of the cap extends from $1\frac{1}{2}$ to 2 inches above the crown sheet, so that when it melts, on account of the water being too low, there will still be enough water left to protect the sheet from being overheated, or *burned*, as it is often called.

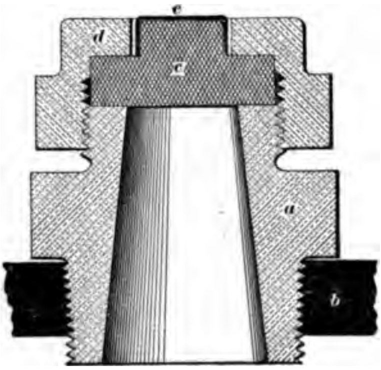


FIG. 18

34. In horizontal return-tubular boilers, the plug is usually placed in the back head 3 inches above the upper row of tubes. In flue boilers of the two-flue type, one plug is screwed in each flue at its highest point, or in the back head at a level about 2 or 3 inches above the top of the flues. The latter practice is considered the better, since it will give warning of shortness of water before the flues become uncovered. In firebox boilers, the plug is screwed into the highest point of the crown sheet. In vertical boilers, it is usually screwed into one of the tubes about 2 inches below the lowest gauge-cock. In water-tube boilers, it is located usually in the shell of the steam drum. In general, it should be so located that it will prevent, by the warning it gives, the overheating of the parts within the fire-line.

STEAM-DRYING DEVICES

35. When horizontal return-tubular boilers are installed in the basements of buildings, there is rarely sufficient head-room for a steam drum or steam dome. Furthermore, the value of these two steam receptacles, so far as insuring a

drying of the steam is concerned, is problematical at best. It is the tendency today to discard steam domes and steam drums, installing slightly larger boilers in order to get the steam space, and fitting inside of them some form of *dry pipe* to insure dry steam. A **dry pipe,** as is apparent from the statement just made, is a device for removing moisture from the steam before it leaves the boiler. Dry pipes are today fitted to all types of power boilers, if so ordered.

36. One of the simplest forms of dry pipe is known as the *Worthen dry pipe*. It is not strictly a dry pipe, but a baffle plate. As shown in Fig. 19, it is a trough *a* made of light sheet iron, and extends from the front to the rear head of the boiler. The steam rising from the surface of the water is forced by the trough to change its direction of flow before entering the outlet pipe *b*, and is supposed to deposit its moisture in the trough, whence it drains back into the water. While this drying device undoubtedly takes out some moisture if the steam is very wet, it cannot be claimed to be particularly efficient. It is better, however, than no provision at all for drying.

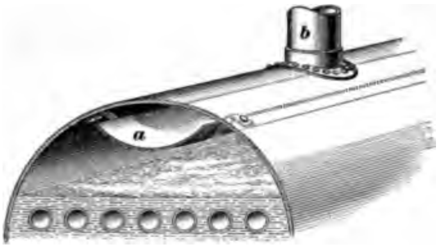


FIG. 19

37. A quite efficient, simple, and much-used form of dry pipe is shown in Fig. 20. It is made from a **T** *a*, which is attached to the steam outlet by a nipple, and two pipes *b*, *b*, slotted on top and having their ends closed by caps *c*, *c*. The steam enters through the slots on top, and, striking against the bottom of the pipe, deposits the water globules. The water collecting in the dry pipe drains back into the water space through drip pipes *d*, *d*. The combined area of the slots should be about one-third greater than the area of the outlet pipe *e*.

38. The Potter steam-drying device, or **mesh separator,** is placed within the boiler. It consists of a circular

chamber with its axis horizontal; one end is connected to the steam outlet pipe. The chamber contains a number of brass-wire mesh screens through which the steam is constrained to flow in succession. On being dashed against these screens, the water globules adhere to them and trickle down to the bottom of the chamber, whence the water is drained back to the water space through a drip pipe.

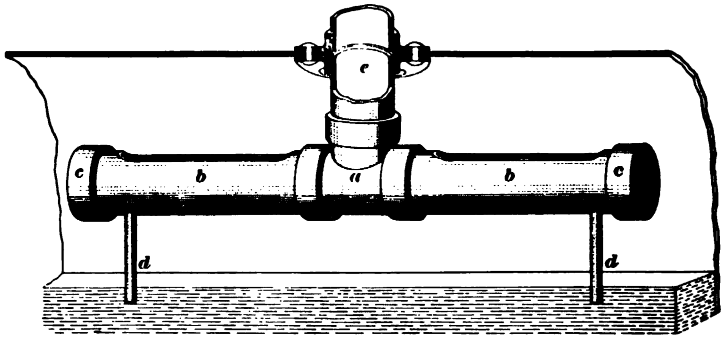


FIG. 20

39. The De Rycke steam-drying apparatus, shown in Fig. 21 as applied to the inside of a steam drum of a water-tube boiler, consists of a combination of two dry pipes *a*, *a*, with two centrifugal steam separators *b*, *b*. The steam enters the two dry pipes through the slots on top and deposits some of its moisture on the sloping bottom, whence it flows toward the receiving chamber *c*. The steam passes from the dry pipes into the separators, where it is given a spiral motion by the curved vanes shown. The centrifugal force generated throws the entrained water against the sides of the separators, whence it drains to the sloping bottom and into the receiving chamber, from which it is conveyed by a drip pipe *d* to the water space. A number of small holes are drilled through *d* at *e* to admit steam from the steam space of the boiler directly to the drip pipe; this insures equal pressures inside and outside of the drip pipe, in consequence of which there is no danger of water being forced into *c*. While the boiler is not delivering any steam, i. e., when

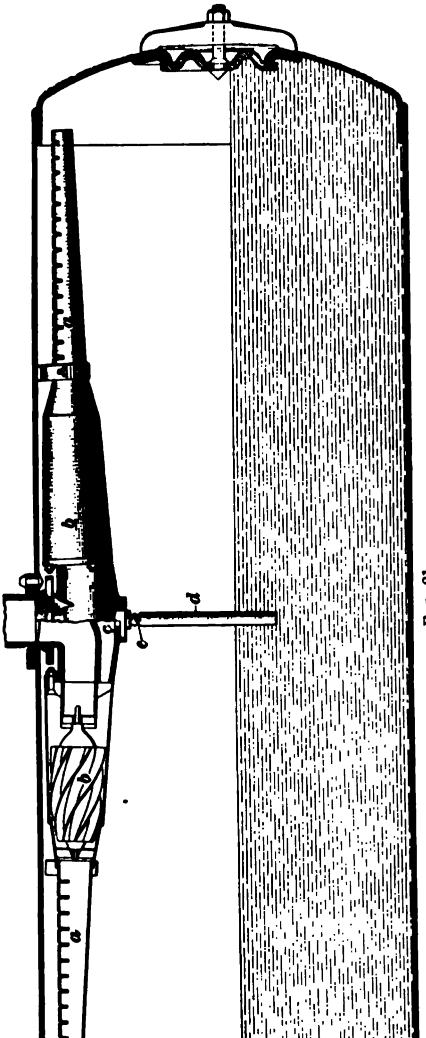


Fig. 21

the main-stop valve is closed, the pressures in c and in the steam space of the boiler are equal; when the stop-valve is suddenly opened, however, the current of steam flowing rapidly through the separator tends to create a lower pressure in c than exists in the steam space by sucking the steam from c, as it were. This tendency is overcome by admitting steam through the holes in d. With steady running this tendency does not exist.

40. In horizontal boilers the ebullition at the surface of the water is especially noticeable at the sides, the water being carried up for some distance partly by the ebullition and partly by capillary attraction. The ascending steam is liable to pick up the drops of water hanging to the boiler shell and thus become moist. To prevent the water from creeping up on the sides to any great extent, so-called bafflers

are occasionally fitted. These are angle irons extending the whole length of the boiler directly above the water-line, and riveted to the shell. It is rather doubtful whether their use has an appreciable influence on keeping the steam dry.

FEEDING AND CLEANING APPARATUS

FEEDPIPING

41. The pipe system through which a boiler or boiler plant receives its water supply may be divided into two parts: the *external system* and the *internal system.*

The external system comprises the piping required to take the feedwater from its source of supply and deliver it at the boiler. The internal system consists of the pipes leading from the outside of the boiler to the point of delivery.

42. The **external feed system** comprises the suction pipe of the feed-pump or injector and the delivery pipes or feedpipes that deliver and distribute the water to the different boilers. As to the arrangement of the suction pipes, they should be as short and free from bends as it is possible to make them, especially when the water must be lifted some distance from a well or similar source of supply. In general, it is very difficult to lift water to a greater height than 24 feet at sea level, unless the pump is in excellent condition; if the water must be lifted higher, it is usually better to locate the pump farther down, excavating for it if necessary. The suction pipes should also be perfectly airtight. When the feedwater is taken from a city water supply, it usually comes to the pump or injector under some pressure; the feed apparatus can then be located where most convenient.

43. The arrangement of the feedpipes naturally depends on the number of boilers to be supplied by the feed apparatus and on the extent to which the pump or injector is required to supply water to any one or all of several boilers.

A good piping arrangement for a horizontal return-tubular boiler is shown in Fig. 22 in diagrammatic form. The feedpipe enters the front boiler head in the middle, directly above the top row of tubes. An elbow is placed at *a*, and the pipe is carried through the setting, a cross being placed at *b*. The pipe is now dropped sufficiently low to bring the stop-valve *c* into a convenient position. A cross is placed at *d*. A check-valve *e*, preferably of the horizontal swing-check pattern, prevents the return of the feedwater. Beyond the

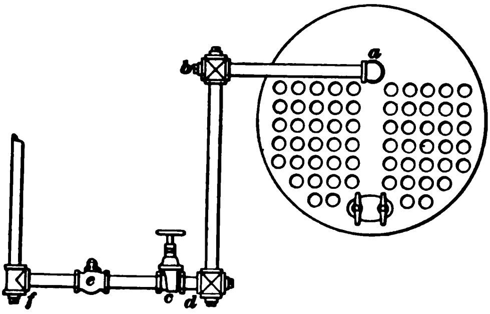


Fig. 22

check-valve the pipe may be run as considered most convenient to reach the boiler feeder. The openings in the crosses *b* and *d*, and in the **T** *f*, opposite the pipes, are closed by brass plugs. On removing these plugs, the pipes can be cleared of sediment by running a rod through them.

Where feedpiping passes through the wall of the setting, or is exposed to the gases of combustion, extra heavy piping and fittings or brass piping and brass fittings should be used.

44. In Fig. 23 is shown an ordinary method of arranging the feedpipes where two boilers are supplied by the same boiler feeder. The main pipe *PP* running along the front of the boilers receives the feedwater discharged from the boiler feeder. Each boiler is supplied by a branch from the pipe *P*, entering the front head *C*. Each of these branches is provided with a stop-valve *A* and a check-valve *B*. The stop-valve shuts off the water from the boiler, while the

check-valve allows the water to enter when the stop-valve is open, but prevents its return.

The stop-valve should always be placed nearest the boiler, thus allowing the check-valve to be examined and repaired

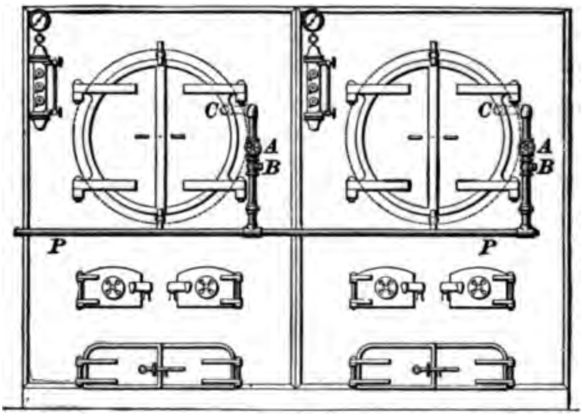


FIG. 23

without shutting down the boiler. With the arrangement of feedpiping shown, the feedwater can be delivered simultaneously to both boilers or to either boiler separately.

45. An arrangement of feedpiping for a plant having six boilers in two batteries, and two independent feed-pumps, is

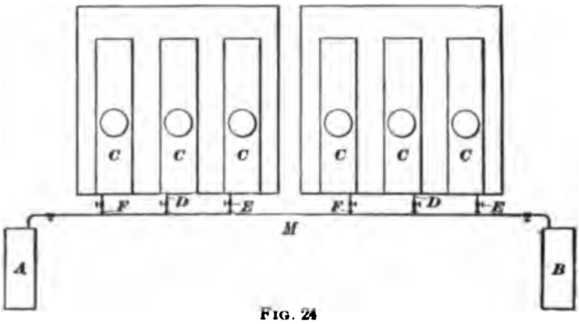


FIG. 24

shown in diagrammatic form in Fig. 24. Both of the feed-pumps shown at *A* and *B* are connected to the main feed-pipe *M*. This pipe has six branches, as *D*, *D*, one for each

boiler. Each branch pipe has its own stop-valve *E* and check-valve *F*. There are two valves in the main feedpipe, one between each pump and the nearest branch pipe. With this arrangement, either or both pumps may be used for any or all boilers. Thus, if it is desired to use the pump *A* for all boilers, the valve in the main feedpipe near this pump is opened and the valve near the pump *B* is closed. The pump *A* will then deliver into any or all of the six boilers, depending on the manipulation of the stop-valves in the branch pipes.

46. When the feedwater goes through a feedwater heater before entering the boilers, it is usually advisable to provide by-pass connections, so that in case of accident to the heater it may be cut out of service without interference with the feeding. In many plants, the entire feed system is fitted in duplicate, in order to be prepared for emergencies. One system may then be supplied by injectors and the other by pumps.

47. The **internal feed system** is arranged in various ways. Its purpose is twofold: (1) to conduct the water to the proper point of discharge in the boiler; (2) to heat the relatively cold feedwater to nearly the temperature of the water in the boiler. As to the proper point of discharge, authorities differ considerably. Most engineers believe that the water should be discharged into the coolest part of the boiler and should be diffused by delivering it through a perforated pipe. Others discharge the feedwater into the steam space and use some suitable spraying device to break the entering stream into spray.

When discharging into the water space of horizontal tubular boilers, a common and very satisfactory arrangement is to make the feedpipe enter the front head a little below the water-line and carry it to within a few inches of the rear head. The end of the pipe is closed and a number of holes in the bottom of the pipe discharge the water downwards between the tubes. Or the water may enter through the bottom of the rear head; a horizontal pipe then carries it to within a few inches of the front head. It then passes

through a vertical pipe up between the tubes to within a few inches of the water level, and returns to the rear through a horizontal pipe and is discharged downwards between the tubes. With this arrangement, the feedwater will be heated to the same temperature as the water in the boiler.

In cylinder boilers, the feedwater usually enters the bottom of the front head. In good practice, it is then carried to the rear by a horizontal pipe and discharged upwards. In some plants this is not done, however, and the water is discharged directly on the crown sheet. This is considered very poor practice by many engineers, since it will subject the plate exposed to the most intense heat to severe local stresses, which ultimately will strain the metal beyond its elastic limit and cause a rupture. In general, it is the common rule that feedwater should never be discharged on the parts of the boiler exposed to the most intense heat, nor should it be delivered in a solid stream against a plate, and, furthermore, it should be discharged in such a direction as to assist the circulation.

In flue boilers, the water may be discharged in the same manner as in return-tubular boilers. In vertical boilers it is usually discharged into the water leg at the lowest point, although sometimes it is delivered about 2 feet above the crown sheet. In boilers of the locomotive type, it may be delivered into the lower part of the cylindrical part or into the water legs below the grate. In water-tube boilers, the builders always determine where to discharge the feedwater, and their advice should be followed.

In low-pressure heating boilers, the feedwater is generally discharged into a header at the bottom, either at the rear end or at the side. The manufacturers of these boilers always decide where the feedwater should enter their boiler, and frequently provide a tapped boss at the point decided on.

FEEDING APPARATUS

48. Injectors and Their Construction.—An **injector** is a steam-actuated device for feeding high-pressure boilers. Its advantages, in comparison with pumps of equal capacity,

are cheapness, small space occupied, absence of exhaust piping, and delivery of hot feedwater. Its disadvantages are that it will not start on pressures less than it is designed for, that it will stand but little abuse, and that gritty water will rapidly destroy it.

The term *range*, when applied to an injector, refers to the steam pressures at which the device will begin and cease working. The range decreases with any increase in the distance the water must be lifted, and with any increase in the temperature of the water supply. The ranges of injectors of different makes are given in the catalogs of their manufacturers.

49. Injectors may be divided into two general classes: the *non-lifting* and *lifting injectors*. They differ from each other, as implied by the name, in that the one class is capable of lifting the water from a level lower than its own, which the other class cannot do.

Non-lifting injectors are intended for use where there is a head of water available, consequently they must be placed below the water level of the supply tank, if one is used. When the water comes to a non-lifting injector under pressure, as from a city main, it can be placed in almost any convenient position close to the boiler. Non-lifting injectors resemble the lifting injector so much in their action that no description of them will be given.

Lifting injectors are of two distinct types, called *automatic* and *positive* injectors. Since positive injectors generally have two sets of tubes, they are frequently called *double-tube* injectors.

Automatic injectors are so called from the fact that they will automatically start again in case the jet of water is broken by jarring or other means. They are simpler in construction than double-tube injectors, and for a moderate temperature of feedwater supply and not too great a range in steam variation answer very well. They are very generally used on stationary and portable boilers and traction engines.

Positive, or double-tube, injectors are provided with two sets of tubes, one set of which is used for lifting the water, while the other set forces the water thus delivered to it into the boiler. A positive injector has a wider range than an automatic injector and will handle a hotter feedwater supply. It will also lift water to a greater vertical height than the automatic injector.

50. The construction of the *Penberthy automatic injector* is shown in Fig. 25. Steam from the boiler enters the nipple *V* and passes into the nozzle *R* and then into the conical combining tube *S*. In rushing past the annular opening between *R* and *S*, it creates a partial vacuum and

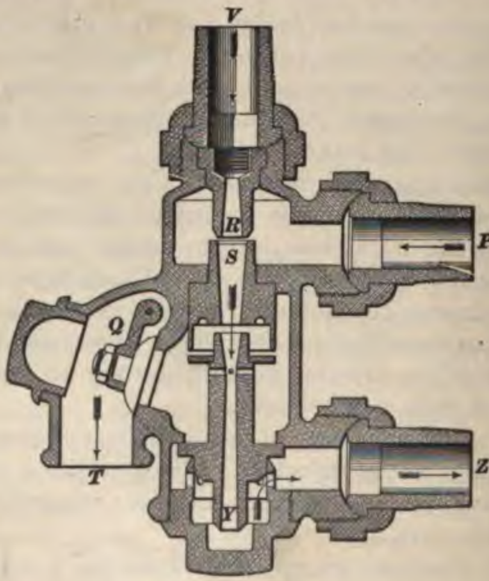


FIG. 25

causes water to flow through *P*, filling the space surrounding the lower end of *R* and upper end of *S*. The nipple *P*, which is shown at the right-hand side, is really situated in the rear. At first the mingled steam and water, by reason of the water not having acquired sufficient momentum, do not flow to the boiler; but after the tube *Y*, the space surrounding

it, and the feed-delivery pipe attached to the nipple *Z* are filled, the mingled steam and water force the swing check-valve *Q* and pass through the overflow *T*. As soon as the jet of water passing through the combining tube has acquired sufficient momentum, the boiler check-valve is forced open and the water commences to enter the boiler. In consequence, no more water will enter the space around the lower end of *S* and the upper end of *Y*, and there being no pressure in this space, the overflow valve *Q* will close. The overflow valve is kept closed by the atmospheric pressure on top of it, for while the injector is working steadily, there will be a partial vacuum in the space around *S* and *Y*.

To start the injector, all that is required is to turn on the steam and water. If the steam supply is too great, steam will issue from the overflow; if the water supply is too great, water will issue. Should the jet of water be broken, i. e., fail to enter the boiler, the overflow valve will lift and the mingled water and steam will come out of the overflow until the jet has acquired sufficient momentum to enter the boiler again, when the overflow valve will close.

The automatically closing overflow valve is the distinguishing feature of the automatic injector, and in some form or other is found in all instruments of this class.

51. Fig. 26 shows the *Hancock inspirator*, which is one of the earliest types of a double-tube injector. The term "inspirator" applied to it is merely a trade name. Steam from the boiler enters through the pipe *a* and flows through the steam nozzle *n* into the combining nozzle *o*, thereby causing water to flow up the pipe *b* into the lifting side of the instrument. The water then passes in the direction of the arrows to the forcing side of the instrument, entering at the top of the forcing tube *s*, where it is met by a jet of steam flowing through the forcing steam nozzle *r* and is further heated and given an increased velocity. It then passes through the pipe *c* to the boiler.

In order to start the instrument, the valve *v* must be closed and the overflow valves *i* and *w* opened. Next, the water

valve *d* and then the steam valve *e* are opened, when the steam will rush through *n*, *o*, *i*, and *w* and out of the overflow until it creates a sufficient vacuum on the left, or lifting, side to cause the water to flow up, which will then discharge out of the overflow. As soon as the water appears, the valve *i* must be closed and the valve *v* opened. Immediately thereafter the overflow valve *w* is to be closed, when the inspirator will be working. To stop the injector, the valves *e* and *v* must be closed and *i* and *w* opened.

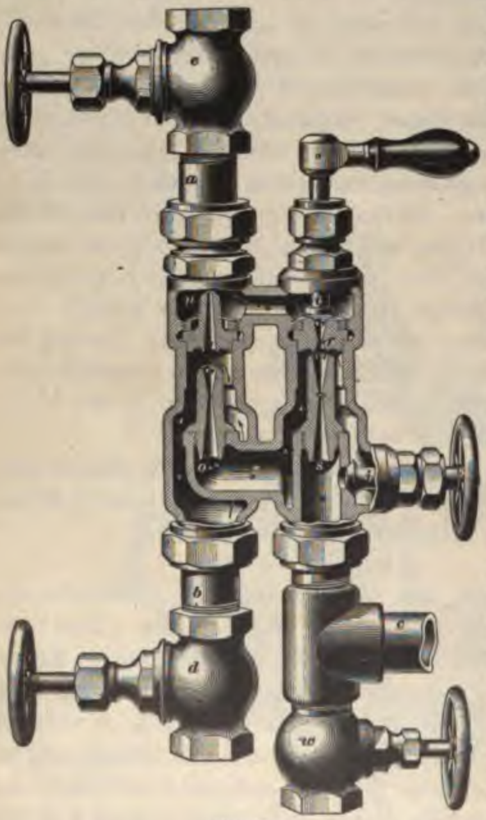


FIG. 26

52. The *Monitor lifting injector* shown in Fig. 27 occupies an intermediate position between the single-tube and double-tube injectors, for while it has two sets of tubes, the one set is used in starting the injector, but is thrown out of action as soon as the injector is working. Steam enters the injector at *F*; the water enters at *P* and passes to the boiler through the nipple *N*; the overflow is at *O*.

The operation is as follows: The water-admission valve *B* is first opened by turning the hand wheel *W*; the primer valve *R* is then opened by the handle *J*, thus permitting steam to flow through the passage *E* and a connection, not

shown in the figure, to the nozzle *u*. From *u*, the steam rushes into the overflow nozzle *O*, which, in conjunction with the nozzle *u*, forms the lifting part of a double-tube injector. A passage connects the chamber surrounding *u* with the space above the overflow valve *L*. The jet of steam rushing from *u* through *O* carries with it some of the air in the chamber to which *O* is connected, thus forming a partial vacuum in the space above the overflow valve, which opens and thus allows the air in *D*, *C*, *G*, *H*, *K*, *T*, and *P* to be

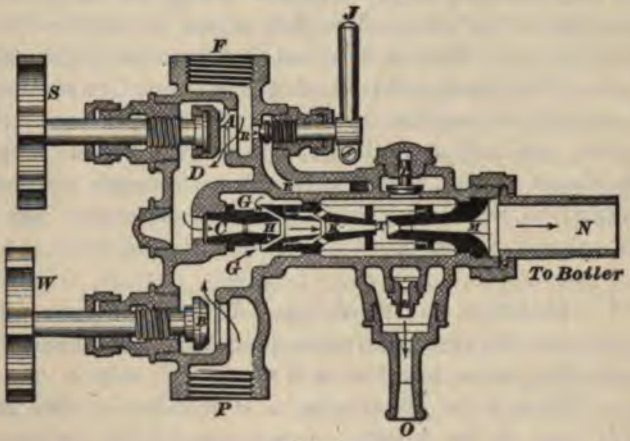


FIG. 27

exhausted. The pressure of the atmosphere now forces the water into the injector, and it finally appears at the overflow. As soon as this happens, the valve *R* is closed, which throws the priming part of the injector out of action. The steam valve *A* is now opened by turning the wheel *S*, which admits steam to the nozzles of the injector proper. At first the water will come out of the overflow, but as soon as the velocity has become high enough, it will enter the boiler, the overflow valve *L* closing automatically.

53. The injectors described in Arts. **50** to **52** are intended to use live steam; there are injectors in the market, however, that make use of exhaust steam. Their principle of action is the same as that of live-steam injectors, from

which they differ only in the relative proportion of the nozzles. Injectors designed to be used with exhaust steam generally will not work against boiler pressures exceeding 75 pounds; there are so-called **high-pressure exhaust-steam injectors** in the market, however, in which live steam can be introduced in order to adapt the exhaust injector to high boiler pressures.

Since exhaust steam is available only when the engine is running, it is necessary to furnish an exhaust injector with a live-steam connection in order that it may be used when the engine is not working. The live steam is throttled so that it will enter the injector at about the pressure of the exhaust steam. The mere addition of a live-steam connection will not convert an exhaust injector into a high-pressure exhaust injector, nor will an exhaust injector work when supplied with steam at full boiler pressure. Likewise, an injector designed to work with full boiler pressure will not work with exhaust steam.

54. Injector Installation.—An injector must always be placed in the position recommended by the maker, for the reason that some injectors will work well only in one position. There must always be a stop-valve in the steam-supply pipe to the injector, which should, for convenience, be placed as close to the injector as is possible. While lifting injectors, when working as such, scarcely need a stop-valve in the suction pipe, it is advisable to supply it. When the water flows to the injector under pressure, a stop-valve in the water-supply pipe is a necessity. A stop-valve and check-valve must be placed in the feed-delivery pipe, with the stop-valve next to the boiler. The check-valve should never be omitted, even though the injector itself is supplied with one. No valve should ever be placed in the overflow pipe, nor should the overflow be connected directly to the overflow pipe, but a funnel should be placed on the latter so that the water can be seen. This direction does not apply to the inspirator or to any other injector that has a hand-operated separate overflow valve. In the inspirator the

overflow pipe is connected directly to the overflow, but the end of the pipe must be open to the air. In general, where the injector lifts water it is not advisable to have a foot-valve in the suction pipe, as it is desirable that the injector and pipe may drain itself when not in use. It is a good idea to place a strainer on the end of the suction pipe.

The steam for the injector must be taken from the highest part of the boiler, as it is essential to the successful working of the injector that it be supplied with dry steam. Under no consideration should the steam be taken from another steam pipe; the injector should always have its own independent steam-supply pipe. The suction pipe should be as straight as possible and must be absolutely air-tight. A very important consideration in connecting up an injector is to have the pipes cleaned by blowing them out with steam before making the connection, since quite a small bit of dirt getting into the injector will interfere seriously with its working. It is recommended to always so locate the injector that the steam pipe, suction pipe, and feed-delivery pipe will be as straight and as short as possible.

In some cases, especially with horizontal boilers without a dome, it is advisable to use a so-called supplementary dome, which is simply a vertical piece of, say, 2-inch pipe about 12 to 18 inches long; the injector steam pipe is then connected to the top of this supplementary dome.

55. Most engineers prefer to select a size of injector having a capacity per hour about one-half greater than the maximum evaporation per hour, in order to have some reserve capacity. The maximum evaporation of power boilers, when not known, may be estimated in Winchester gallons (231 cubic inches) by one of the following rules, which hold good for ordinary combustion rates under natural draft:

Rule 1.—*For plain cylindrical boilers, multiply the product of the length and diameter, in feet, by 1.3.*

Rule 2.—*For tubular boilers, either horizontal or vertical, multiply the product of the square of the diameter, in feet, and the length, in feet, by 1.9.*

Rule 3.—*For water-tube boilers, multiply the heating surface, in square feet, by .4.*

Rule 4.—*For boilers not covered by the foregoing rules, multiply the grate surface, in square feet, by 12.*

Rule 5.—*If the coal consumption, in pounds per hour, is known, it may be taken as representing the number of gallons evaporated per hour.*

As there is no standard method of designating the size of an injector that is followed by all makers, such an instrument must be selected from the lists of capacities published by the different makers.

56. Automatic Water Feeder.—In low-pressure heating work the condensed steam is returned to the boiler by gravity, but owing to leakage of the pipe-system connections and loss at the radiator air vents, less water is returned to the boiler than is sent out in the form of steam. This results in a gradual lowering of the water level in the boiler, and necessitates a frequent replenishing. It is very desirable that this be done automatically, and different devices for this purpose are on the market.

A simple form of **automatic water feeder** and pipe connections thereto is shown in Fig. 28. It is essentially composed of a cast-iron casing *a* in which a ball float *b* is attached to the end of a lever that turns on the fulcrum pin *c*, and controls the flow of water to the boiler. The pipe *d* connects with the cold-water supply pipes in the building. The branch *e* connects to the inlet tapping of the feeder casing, and discharges the water through the valve *f* when the float has fallen sufficiently to open the valve. When enough water has entered the boiler to raise the water-line to the level indicated by the dotted line, the valve will be closed by the float *b*. The feeder should be set so that its center line will be exactly level with the desired water-line of the boiler. Water from the feeder enters the boiler through the pipe *g*, and steam enters the feeder casing through *h* from the top of the boiler. A by-pass valve, or cock, *i* may be opened

slightly to feed the boiler slowly in case the automatic feeder needs repairs. This cock should never be opened, however, except in such an emergency. It is advisable to place a check-valve *k* on the feedpipe *d* to prevent boiler water from being forced into the street mains through the by-pass.

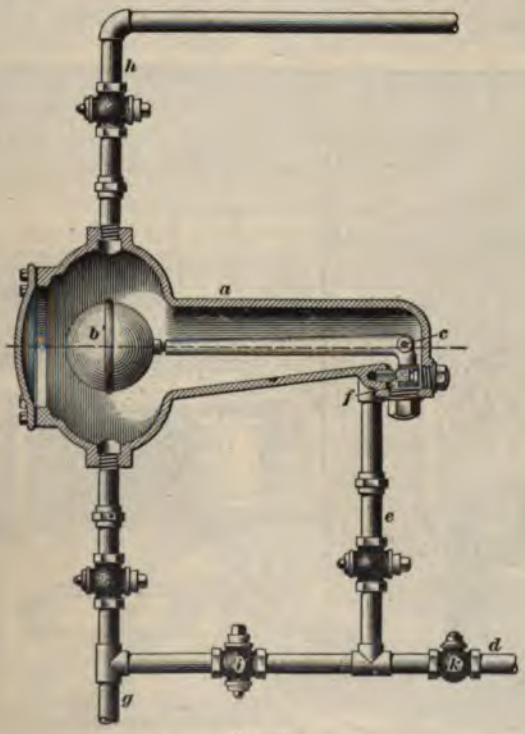


FIG. 28

57. Steam Loop.—A certain apparatus, consisting essentially of pipes, and used for automatically returning the water of condensation from a steam pipe, steam-heating system, steam separator, etc. to the boiler, is known as the **steam loop.** Its construction when applied to a separator is shown in Fig. 29, and if its principle of operation is understood, the loop can easily be modified to suit different conditions.

The loop consists essentially of a *riser d*, a *bend i* acting as a check, a so-called *horizontal e*, a *drop leg f*, and a check-valve and globe valve in the pipe connecting the drop leg to the boiler. The check-valve opens toward the boiler, and should never be omitted.

The operation of the loop is as follows: Owing to the condensation of the steam, the pressure in the horizontal *e*

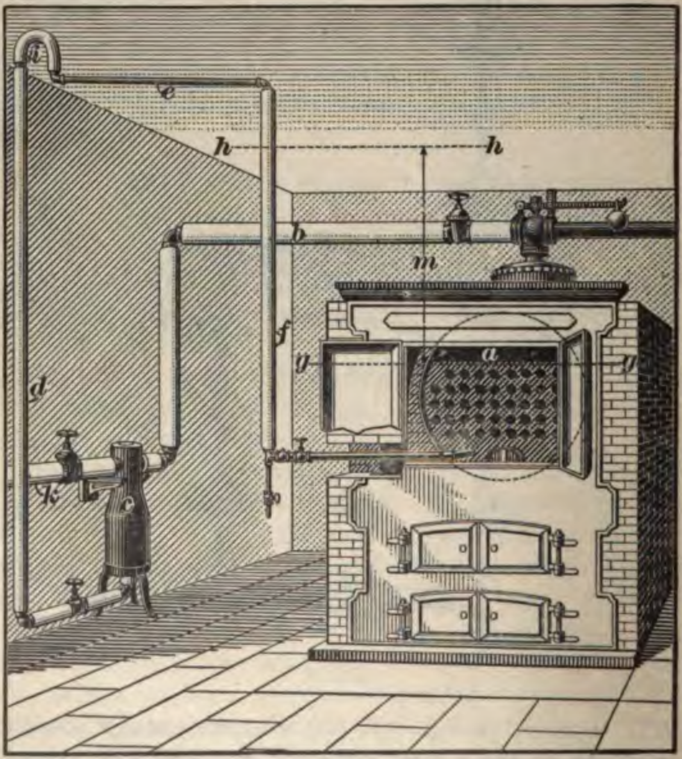


FIG. 29

is slightly less than in the separator. In consequence, there will be a flow of steam up the riser *d* and through the bend *i* into the horizontal, and thence into the drop leg. Any water collected in the separator will be carried along, and as the bend *i* prevents its return to the riser, this water flows along

the horizontal into the drop leg. The water continues to rise in the drop leg until the pressure due to its head being added to the pressure in the horizontal is sufficient to overcome the pressure within the boiler. The check-valve is now forced open and the water flows into the boiler until the water in the drop leg has dropped so low that the pressure exerted is insufficient to force the water into the boiler. The check-valve then closes. The head of water is measured between the water level *g g* of the boiler and the level at which the water stands in the drop leg. Thus, if the water stands at the level *h h*, the head is given by the distance *m*. This distance, from which the height of the drop leg can be determined, depends on the difference in pressure existing at the separator and the boiler pressure. In practice, about 2.5 feet should be allowed for each pound difference in pressures. As steam loops are liable to become air locked, or flooded with water and thus rendered inoperative, their use is not recommended in places where there is not a skilled engineer in charge.

CLEANING APPARATUS

58. Bottom Blow-Off.—For the double purpose of emptying the boiler when necessary and of discharging the loose mud and sediment that collects from the feedwater, each boiler is provided with a pipe that enters the boiler at its lowest point. This pipe, which is provided with a valve or cock, is commonly known as the **bottom blow-off.** The position of the blow-off pipe varies with the design of the boiler; in ordinary return-tubular boilers, it is usually led from the bottom of the rear end of the shell through the rear wall. Where boilers are supplied with a mud-drum, the blow-off is attached to the drum.

59. While many boiler plants use globe valves on the blow-off pipe, their use is objectionable, since though tightly screwed down, the valve may not be properly closed on account of a chip of incrustation or similar matter getting between the valve and its seat. As a result, the water may leak out of the boiler unperceived. Formerly, brass plug

cocks were used almost entirely, which, owing to their habit of sticking tightly, were superseded by globe valves and gate valves for high-pressure boilers. Brass plug cocks are still used for low-pressure boilers, and prove quite satisfactory.

Within the last few years plug cocks packed with asbestos have been placed on the market, the asbestos packing removing the objectionable features of the plug cock. Many engineers now insist on the use of these cocks for the blow-off pipe. Gate valves are also used to some extent, but are open to the same objection as globe valves. In the best modern practice, the blow-off pipe is fitted with two shut-off devices. The one shut-off may be an asbestos-packed cock and the other some form of valve, or both may be cocks or valves, the idea underlying this practice being that leakage past the shut-off nearest the boiler will be arrested by the other.

60. The bottom blow-off pipe, when exposed to the gases of combustion, should always be protected by a sleeve made of pipe, by being bricked in, or by a coil of plaited asbestos packing. If this precaution is neglected, the sediment and mud collecting in the pipe, in which there is no circulation, will rapidly become solid. Instances are not rare where the blow-off pipe has become so badly choked that on opening the blow-off cock the full steam pressure could not clear the pipe.

The blow-off pipe should lead to some convenient place entirely removed from the boiler house and at a lower level than the boiler. In some places, the blow-off may be connected to the nearest sewer; in many localities, however, ordinances prohibiting this are in force; the blow-off is then connected to a cooling tank, whence the water may be discharged into the sewer. When the blow-off has been used for the purpose of partly emptying the boiler, the greatest care should be used to make sure that the cock or valve is properly closed. If there is a leak, it can be discovered by feeling the blow-off pipe at some distance from the boiler.

61. A good arrangement of the bottom blow-off for a return-tubular boiler is shown in Fig. 30. The blow-off

pipe *a* has two right-angle bends of ample radius, which render it springy. It is connected to the bottom of the boiler by a nipple screwed into the flange *b* and a right-and-left coupling. A pipe sleeve *c* protects the part of the pipe

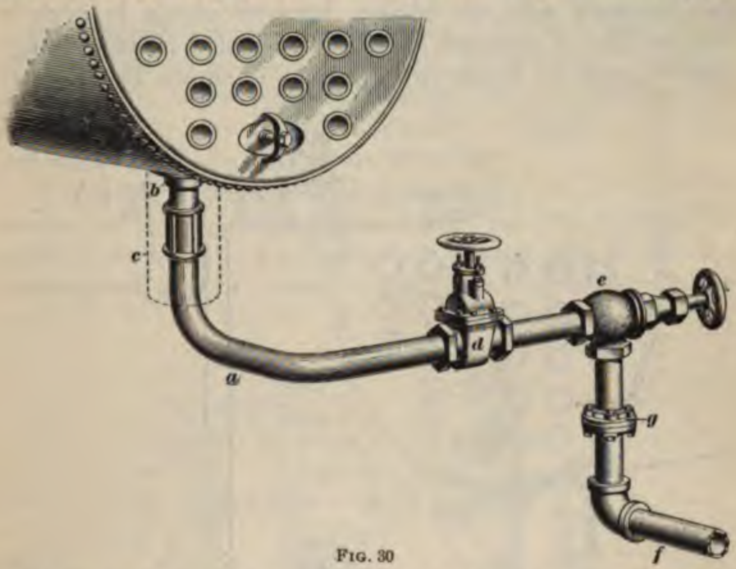


FIG. 30

that would otherwise be exposed to the hot gases of combustion. A gate valve *d* and angle valve *e* form shut-offs. The pipe *f* leading to the sewer, or blow-off tank, is connected to the valve *e* by nipples of suitable length and a flanged union *g*.

62. The usual diameters of blow-off pipes for tubular boilers are as follows: 1½-inch pipe for boilers up to 42 inches in diameter; 2-inch pipe for diameters up to 60 inches, and 2½-inch pipe for larger power boilers. In low-pressure and water-tube boilers, the size of the blow-off is determined by the manufacturers, a tapped boss at the lowest point defining the size of pipe to be used.

63. Surface Blow-Off.—Boilers are often fitted with a **surface blow-off,** which is simply a pipe with a scoop-shaped fitting placed 3 or 4 inches below the water level.

The pipe is provided with a cock or valve. The surface blow-off serves to remove floating impurities that would finally settle and fall to the bottom of the boiler if not removed. The surface blow-off piping can advantageously be combined with the bottom blow-off piping in such a manner that a constant circulation obtains in the piping. The manner in which this is done is shown in Fig. 31,

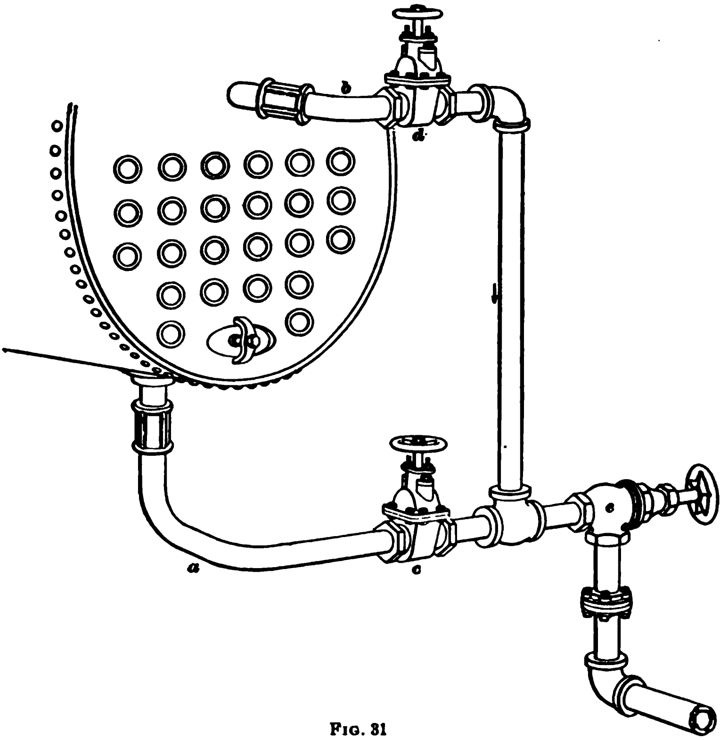


Fig. 31

where *a* is the bottom blow-off having two right-angle bends of ample radius, and *b* is the surface blow-off, connecting to the bottom blow-off beyond the valve *c*. When neither blow-off is in use, the valves *c* and *d* are open, but the blow-off valve *e* is tightly closed. The water then circulates in the direction shown by the arrow. This circulation is quite rapid, and prevents the accumulation of sediment in the

blow-off pipe and its subsequent rapid destruction by overheating. To use the surface blow-off, the valve *c* is closed and the valves *d* and *e* are opened. To use the bottom blow-off, the valve *d* is closed and the valves *c* and *e* are opened.

64. Manholes and Handholes.—For the purpose of allowing the inside of the boiler to be examined, cleaned, and repaired, holes closed by suitable covers are cut into the head or shell. When of sufficient size to admit a man, they are called *manholes;* otherwise, *handholes.*

A common construction of a **manhole** and its cover is shown in Fig. 32. An elliptical hole is cut into the head or shell of the boiler. A wrought-iron or steel ring *R*, called a *compensation ring*, is riveted to the plate *P*, generally on the

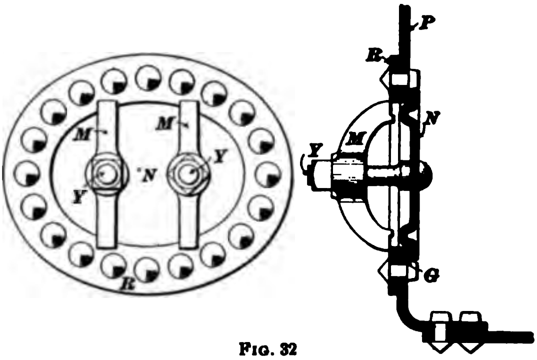


FIG. 32

outside, for the purpose of strengthening the plate, which is weakened considerably by the cutting of such a large hole through it. A cover *N* made of wrought iron, cast iron, or steel is fitted to the hole, inside of the boiler, and is provided with two studs *Y*, *Y* riveted to it. This cover is flanged and overlaps the edges of the plate about 1 inch or more all around its perimeter. A yoke *M* is slipped over each stud, its two extremities resting on the compensation ring. A ring *G*, or *gasket*, as it is commonly called, made of sheet rubber or any other pliable waterproof material, is placed between the plate and the cover and serves to make a water-tight joint.

Of late years it has become quite generally the practice to flange the head inwards and face its edge, thus doing away with the necessity for the compensation ring. When the manhole is in the shell, in the best modern practice, a flanged compensation ring is riveted to the inside of the shell, as shown in Fig. 33.

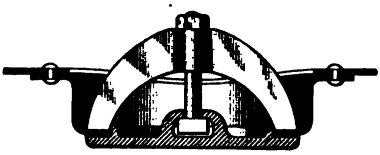


FIG. 33

Manholes are usually made about 11 inches by 15 inches in the clear. If any smaller, it is rather difficult for a man to get through them.

65. Handholes are placed in boilers whose construction does not permit the entrance of a man, as, for example, in vertical boilers. They are also placed in other boilers in convenient positions; thus, in boilers of the locomotive type they are usually placed in the corners of the water legs, and in horizontal return-tubular boilers are often found in the heads below the tubes. The handhole is a convenient place to rake out sediment and scale and to admit a hose for the purpose of washing out the boiler. The handhole and its cover are constructed very much like a manhole and cover; the handhole being smaller, requires but one yoke and bolt to close up the cover.

BOILER SETTING AND CHIMNEY FITTINGS

BOILER-SETTING FITTINGS

GRATES

66. Grates for Small Heating Boilers.—The **grate,** which is nearly always made of cast iron, furnishes a support for the fuel to be burned and must be provided with spaces for the admission of air. The spaces and supports are alternate and are distributed evenly all over the grate surface. The combined area of all the supports is usually made nearly equal to the combined area of all the air spaces; in other words, half the grate surface is air space and half serves to support the fuel.

The grates in use in low-pressure steam-heating boilers are made in many forms, differing greatly in convenience and durability. A good grate should permit the fire to be cleared of ashes and clinkers thoroughly and without the loss of unburned fuel. Grates are divided into two classes, which are *fixed grates* and *shaking grates.*

67. Fixed grates, as implied by their name, are stationary; they should never be used in low-pressure heating boilers having a fire-pot, because they afford no facilities for cleaning the fire or for removing the refuse when the fire has gone out. The fire can be cleaned only by the use of a poker thrust up through the grate, and by a clinker bar that is shoved through a poke hole in the base of the fire-pot. The fixed grate is the dirtiest and most inconvenient arrangement that can be used for low-pressure heating boilers having a fire-pot.

Fixed grates may be improved somewhat by making the central part removable, as in Fig. 34. The center grate *a* is attached to the bar *b*, and can slide forwards far enough to uncover the central opening in the main grate *d*. This permits the easy removal of large clinkers, or the refuse from a dead fire.

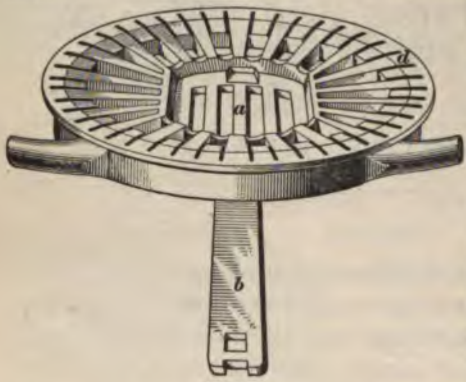


FIG. 34

68. Round grates are often made movable, for the purpose of agitating the fire and cleaning it. Some are constructed to vibrate back and forth on a central pivot, and others are provided with a crank and suitable gearing by which they can be rotated to any extent desired. These devices operate very imperfectly, however, because the movement at the center of the grate is too small to be of much practical use, and because the motion fails to properly agitate the mass of fuel and dislodge the fine ashes that obstruct the heart of the fire.

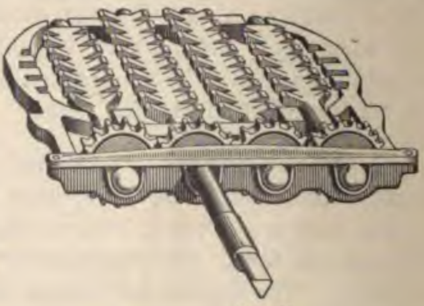


FIG. 35

A **revolving-bar grate** is shown in Fig. 35. It is composed of a series of revolvable parallel bars having lateral fingers, or lugs, that support the fire and constitute the surface of the grate. Each bar is provided with three sets of fingers, and is supported at the front and rear ends in bearings that permit it to revolve. The whole group is revolved simultaneously by means of the gearing shown. The fingers not only shake up and agitate

the coal as the bars revolve, but they break up the bed of ashes that forms at the bottom of the fire, and grind up the clinkers, so that they will pass through into the ash-pit.

These grates have one defect, which, in many cases, is a serious one. The normal position of the bars is shown in Fig. 36, and Fig. 37 shows the positions that are assumed by them in revolving. At the same time that the bars *a* and *b* are nearly touching, point to point, a wide space is opened between *b* and *c*. This opening occurs between each pair of bars when they are merely rocked 30° each way from the normal position. The live coal is very apt to run down

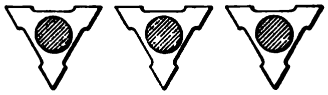


FIG. 36

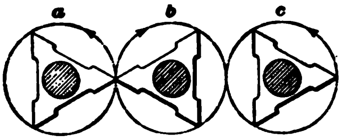


FIG. 37

through these openings into the ash-pit, whereby a considerable waste of fuel is caused. When the bars are in their normal position, as in Fig. 36, the points are separated so far that the smaller sizes of coal, such as chestnut and pea, cannot be used without excessive waste. In revolving the grate, a large quantity of live coal is liable to fall into the ash-pit, thus spoiling the fire, and also in some cases ruining the grate by causing it to warp and finally break.

All movable grates tend to shake the fire, and hence are spoken of as **shaking grates.**

69. Grates for Large Heating and Power Boilers. For large heating boilers and for power boilers, the objections to the fixed grate stated in Art. 67 are not so pronounced as to render it inadvisable to install fixed grates. The furnace door is always, in good construction, on a level with the grate surface, and hence the fire can be cleaned with the ordinary fire-tools.

70. The most common type of grate is made of single bars *A*, Fig. 38, placed side by side in the furnace. The thickness of the lugs cast on the bars determines the width

of the open spaces of the grate. It is the general practice to make the thickness across the lugs twice the thickness of the support. For long furnaces the bars are generally made in two lengths of about 3 feet each, with a bearer in the middle of the grate. Long grates are generally set with a downward slope toward the bridge of about $\frac{3}{4}$ inch per foot

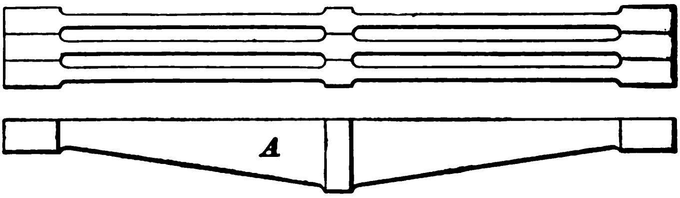


FIG. 38

of length. This facilitates the admission of air to the rear of the grate; it also facilitates cleaning the grate.

Single grate bars are easily broken in transportation and handling; for this reason grate bars are often made as shown in Fig. 39. Two bars are united in a single casting, which is not so fragile as a single bar.

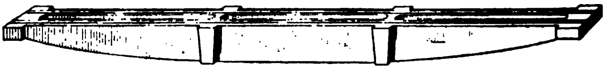


FIG. 39

71. The width of the air space, and hence the thickness of the grate bar, depends largely on the character of the fuel burned. For the larger sizes of anthracite and bituminous coals, the air space may be from $\frac{5}{8}$ to $\frac{3}{4}$ inch wide, and the grate bar may have the same width. For pea and nut coal, the air space may be from $\frac{3}{8}$ to $\frac{1}{2}$ inch, and for finely divided fuel, like buckwheat coal, rice coal, bird's-eye coal, culm, and slack, air spaces from $\frac{3}{16}$ to $\frac{3}{8}$ inch may be used. When these small air spaces are used, the grate, if made as shown in Figs. 38 and 39, must have the bars so thin in proportion to their length that they will warp and twist and a large number of the bars will soon break, especially when the rate of combustion is high. To overcome this objectionable feature, the grate bar shown in Fig. 40, and known as the

herring-bone grate bar, was designed, and in many parts of the country it has almost entirely superseded the ordinary grate bar. Owing to the shape of the supports for the fire, they are free to expand and contract; being quite short and of small depth in comparison to the ordinary grate bar, there is very little danger of excessive warping of the supports.

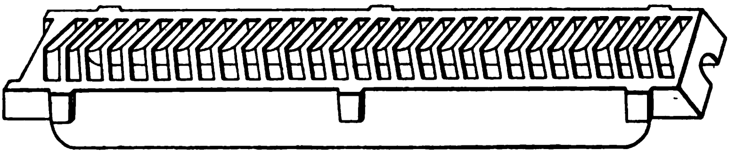


FIG. 40

In consequence, they will usually far outlast a set of ordinary grate bars. Since there are only a few large bars for the grate, it also is easier to replace a broken bar. Herring-bone grate bars can be obtained in a great variety of styles and with different widths of air spaces.

72. In general, a grate bar that is suited for the kind of fuel that is to be burned should be selected. Thus, if finely divided coal is to be burned, a grate bar having small air spaces and supports should be selected, since otherwise a large percentage of the fuel will fall into the ash-pit. On the other hand, for the large sizes of coal, select bars having large air spaces, using the largest air space when caking coals are to be burned. Some varieties of bituminous coal will *cake*, that is, fuse together to a considerable degree, and the ashes and clinkers formed will be of such size that a large part of them cannot pass through the air spaces unless these are large; the grate thus becomes clogged, shutting off the air from the fire. This reduces the rate of combustion and evaporation. When putting in grate bars, they should not be fitted in tightly, but plenty of room should be given to allow them to expand.

73. The front end of the grate bars is usually supported on the *dead plate*, which is a flat cast-iron plate placed across the furnace just inside the boiler front and on a level with the bottom of the furnace door. The purpose of the dead

plate is twofold: (1) it forms a support for the firebrick lining of the boiler front; (2) it forms a resting place on which bituminous coal may be coked before it is placed on the fire. Experience has shown that most bituminous coals can be burned to the best advantage if they are coked first, by being exposed to the radiant heat of the fire. To support the grate bars, the inner edge of the dead plate is either beveled or a lip is provided, as *a*, Fig. 41. The dead plate should be at least 8 inches wider than the furnace, and be

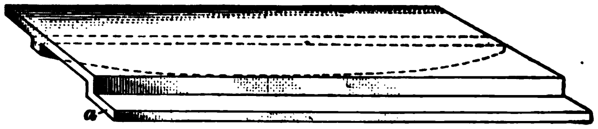


FIG. 41

heavily ribbed to stiffen it. The supporting of the grate bars on a lip of the dead plate is objectionable, as ashes will soon get in between the ends of the bars and the dead plate and become hard, in consequence of which expansion of the grates will push the dead plate against the boiler front and in many cases break it. Too much care cannot be exercised to insert grate bars in such a manner that they can expand freely and without detriment to the boiler setting.

FIG. 42

74. In the best modern practice, the grate bars are supported on *bearing bars*, made as shown in Fig. 42. The ends *a*, *a* are usually built into the side walls of the furnace, but a much better practice is to provide a cast-iron box *a*, Fig. 43, built into the side walls, on the bottom of which the end of the bearing bar *b* rests, as shown. This allows the bearing bar to freely expand and contract, and permits ready renewal.

75. The greatest objection to stationary grate bars is that with them the furnace door must be kept open for a

considerable length of time to allow the fire to be cleaned. Ashes, cinders, and clinkers will collect in the course of time on the grate, shut off the air supply, and thus reduce the amount of steam generated. To restore the fire, it needs to be cleaned. Cleaning fires with a stationary grate is not only a job that severely taxes the fireman, owing to the excessive heat to which he is exposed, but the inrush of cold air chills the boiler plates, thus producing stresses that in the course of time will crack them. To overcome these objections, grates have been designed that allow the fire to be cleaned without opening the furnace door. This is usually done by giving each grate bar a rocking motion.

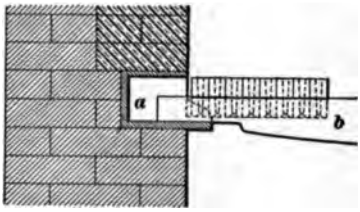


FIG. 43

There are many designs of shaking grates for large steam boilers on the market, differing chiefly in detail and arrangement. Since a description of more than one would be chiefly a repetition, one that clearly exhibits the characteristic features of shaking grates is here described.

76. Fig. 44 shows one form of the *McClave shaking grate*. The grate bars are hung on trunnions at each end and are connected together by bars *a* and *b*. Ordinarily they stand as shown in the right-hand half of the illustration. When it is desired to merely shake the fire and thus remove the bottom layer of ashes, the points *c* are vibrated from the level shown to the lowest position the connections will permit. The points follow the back of the bar immediately in front of them; thus no unusual opening is made through which fine fuel may fall into the ash-pit. The end bar *d* is curved to fit the frame. When the ashes have accumulated to a considerable thickness, or when they have fused together in a mass of clinkers, the points *c* are thrown upwards, as shown in the left-hand half of the illustration, thus forming a series of deep pockets that are closed at the bottom by the main rib, or back plate, of the grate bars. The act of throwing

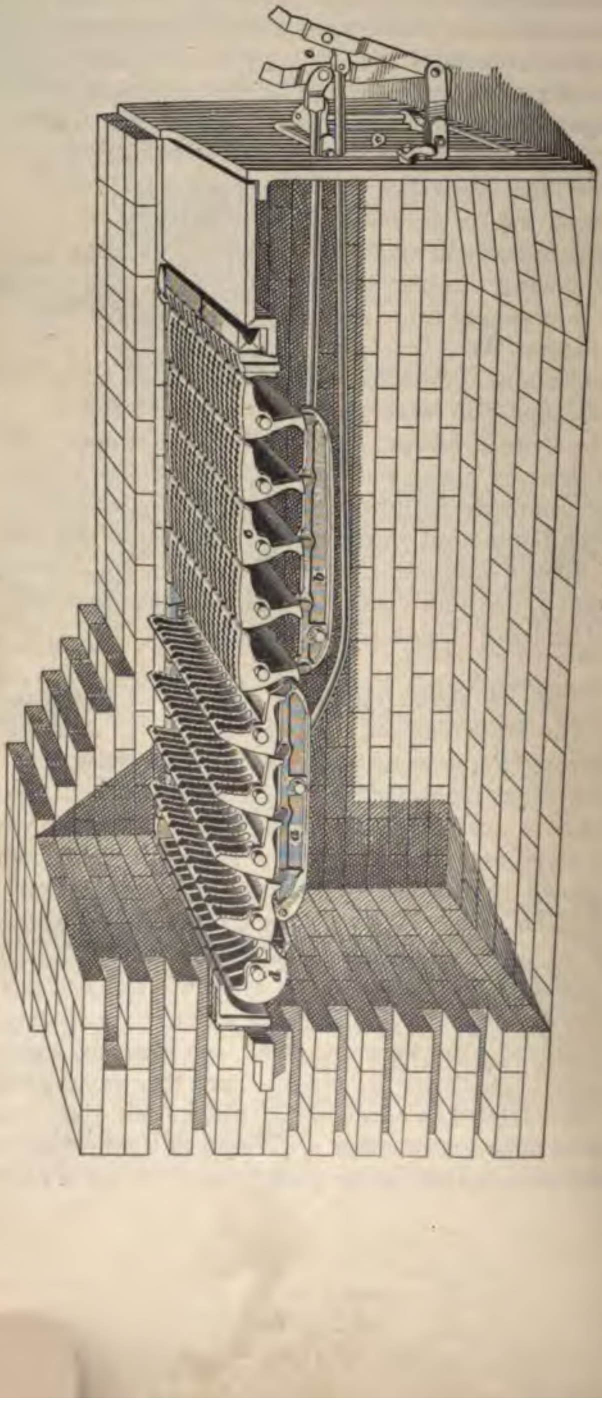


FIG. 44

the points upwards breaks up the fused mass, which drops into the pockets and is discharged when the bars are returned to their normal position. The grate bars are operated by means of a handle fitting the levers, shown at *e*. By means of these levers, either half of the grate can be operated independently. The two levers can be locked together; in that case all the grate bars can be worked back and forth simultaneously.

77. An *Argand steam blower*, shown in Fig. 45, is used in connection with the McClave grate to furnish a forced draft. The blower consists of a long air tube *t* discharging from the end *s* below the grate. In the other end of the tube is placed a ring-shaped tube *r*, perforated on the right with

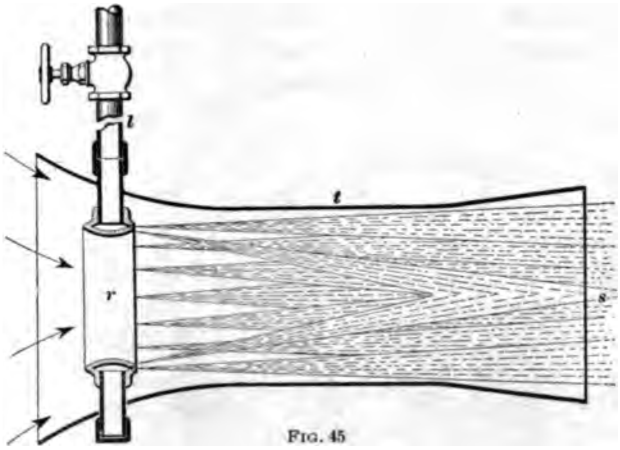


FIG. 45

small holes. Steam from the boiler is led into the ring by the pipe *l*, and escapes in jets through the perforations, carrying air along with it, into the ash-pit. This method of producing a draft by means of an air blast below the grate is particularly valuable in burning the small sizes of anthracite.

FURNACE MOUTH

78. In order that the intense heat of the fire may not destroy the boiler front by warping and cracking it, the front must be protected by a firebrick lining, which is supported

on the dead plate. An arch is formed on a level with the top of the furnace door; this arch is generally supported on a cast-iron plate of suitable form, and known as the **arch plate.** Since the arch plate is exposed to the intense heat of the fire, it will soon burn out unless protected.

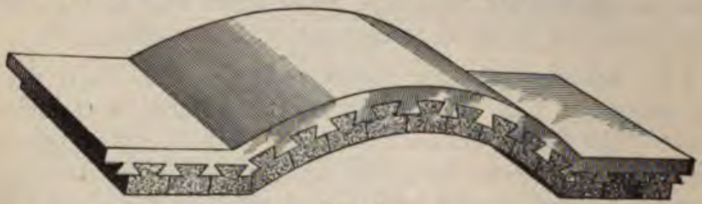


FIG. 46

79. Fig. 46 shows a protected cast-iron arch plate that is on the market. Dovetailed grooves are provided on the fire

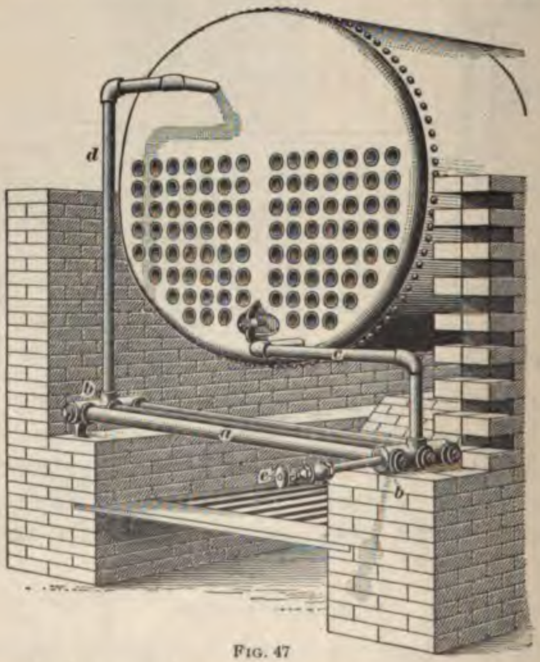


FIG. 47

side, into which specially made firebricks are placed, as shown. These firebricks can be easily renewed when worn out.

80. Some engineers prefer to use a so-called **water arch** instead of a protected arch plate. There are a number of designs of this device on the market, one of which is shown in Fig. 47. This consists of three steel boiler tubes shown at *a*, expanded into headers *b*, *b*, and connected to the water space of the boiler by the pipe *c* and to the steam space by the pipe *d*. The tubes at *a* are set at an inclination, as shown, being higher at the end connected to the steam space, in order to allow the steam generated to escape readily. A blow-off *e* is fitted to the lower header for blowing out mud and sediment. The firebrick lining of the front and over the fire-door is carried on the tubes at *a*.

81. It is sometimes considered desirable to protect the sides of the fire-door opening with cast-iron plates, arranging them as shown in the plan view of a furnace mouth given in Fig. 48, where *a*, *a* are the plates mentioned, which are known as **cheek plates**. In the illustration, the dead plate is shown at *b* and the grate at *c*. Some makers combine the dead plate, arch plate, and cheek plates into one casting. The objection to this is that the whole casting has to be thrown away when only one part, as, for instance, one of the cheek plates, is burned out.

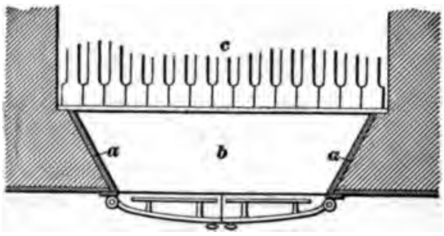


FIG. 48

82. The sides of the furnace mouth should taper from the fire-door opening to the sides of the furnace, as shown in Fig. 48. The ashes and clinkers can then be easily removed, since there is no place in the furnace mouth that cannot be readily reached.

BRIDGE

83. The **bridge** is a low wall at the back end of the grate; it forms the rear end of the furnace. It is usually built of firebrick, though in some cases it is made of wrought

iron, with an interior water space communicating with the inside of the boiler. The office of the bridge is to bring the flame in close contact with the heating surface of the boiler. The passage between the bridge and boiler shell should not be too small; its area may be approximately one-sixth the area of the grate. Likewise, the space between the grate and shell should be ample for complete combustion. Professor Thurston advises that the distance between grate and boiler shell should be one-half the diameter of the shell.

SUPPORTS FOR HORIZONTAL BOILERS

84. Boilers of the horizontal return-tubular type are supported by cast-iron brackets riveted to the shell and resting on iron plates embedded in the side walls, or by straps riveted to the shell and attached to overhead girders supported by the side walls, or by the boiler front at the front end and a saddle or chair below the rear end.

85. When brackets are used, two are placed at each side, one set near the front end and one near the rear end. These brackets, in the best modern practice, are placed above the fire-line and protected by firebrick, it being inadvisable to expose them to fire, owing to the risk of burning them off. Rollers are generally placed between the brackets and the plates they rest on, to provide for easy expansion and contraction. It is a general and good rule to set the boiler so that its expansion and contraction will not disturb the brick setting; in other words, the boiler should never be tied to the brickwork.

86. The method of supporting boilers by straps from overhead girders is used today chiefly for boilers set in a nest, i. e., several boilers over a common furnace. Occasionally this method is employed for single boilers for the purpose of relieving the brickwork of the weight of the boiler and its contained water. The overhead girders are then supported on cast-iron or steel columns. This makes a somewhat expensive setting, which is claimed, however,

to be more free from liability to crack than the setting receiving the weight of the boiler.

87. There are grave objections to supporting the boiler by the boiler front and in a saddle at the rear. In the first place, the boiler front is a thin and large casting of a shape poorly adapted to bear a heavy load, as that due to the weight of the boiler and its water, without buckling and consequent danger of breaking finally. In the second place, the chair at the rear end is exposed directly to the fire and will burn out in course of time, allowing the rear end of the boiler to drop, which may cause an explosion or loss of life through the breaking of the steam pipe.

CHIMNEY FITTINGS

SMOKE-PIPE CONNECTIONS

88. The gases of combustion are conveyed from the boiler to the chimney either by a **smoke pipe**, generally made of sheet iron, or by a brick flue. For small heating boilers, a smoke pipe is generally used. A common method of connecting a small heating boiler to a chimney is shown in Fig. 49. The smoke pipe *a* has a **T** *b* on the bottom which has a removable cover *c*, generally called a *clean-out*, through which soot is removed. Another clean-out *d* allows the soot to be removed from the horizontal pipe leading to the chimney. A damper *e* is placed in the smoke pipe in any convenient position.

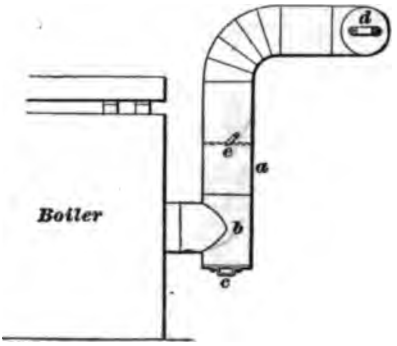


FIG. 49

89. Fire laws require smoke pipes to be kept at least 12 inches away from all ceilings and woodwork, and to be protected or covered with non-conducting covering where

they are placed nearer than this; or, the smoke pipe can be made with a circulating air space by enclosing it in sheet iron. Where the pipe passes through the roofs or wood partitions, it should be fitted with a collar at least 12 inches in diameter larger than the pipe, with a circulating hood or opening, so that the air has free access.

90. For most high-pressure boilers, the smoke pipe is a simple round pipe, which should have an area at least 15 per cent. larger than the combined area of the boiler tubes. When boilers are in a battery and connected to the same chimney, the different boilers are first united to a common duct *a*, Fig. 50, by branches *b*, *b*; the duct *a* and branches *b*, *b* are spoken of as the *breeching*. Each branch must be provided with its own damper, the handles of which are shown

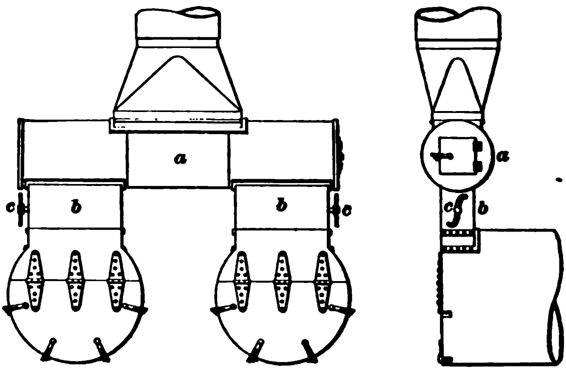


FIG. 50

at *c*. The chimney is either placed directly on top of the duct *a*, as shown in the illustration, or a smoke pipe is led from the breeching to the chimney. Breechings are made in many forms to suit the existing conditions; the illustration given will serve as a suggestion. The area of the duct should equal the combined area of the branches; and the branches should have an area about 15 per cent. larger than the combined area of the tubes.

91. When a brick-set boiler is so placed that its rear end adjoins a brick chimney, a brick flue is often placed on top

of the boiler and joined directly to the chimney. This method may be employed where headroom is too limited to admit an iron breeching and smoke pipe.

92. Smoke pipes, as well as exposed parts of the boiler, should always be covered with some good non-conducting material to prevent loss of heat. Boiler and smoke-pipe coverings are similar to the regulation pipe coverings, and are made in block shape from 1 to 3 inches thick. They are applied to the exposed shell of the boiler, or to smoke flues, by securing them with wire, and then plastering over them to make a smooth air-tight finish. Plastic asbestos is also used. A thin coat of the latter is placed on the shell of the boiler or smoke pipe, and then ordinary coarse wire mesh is bound around and fastened to bond the material, after which a hard thick coat is plastered and troweled smooth.

Some coverings are put on over an air space, this method not only insuring the most perfect insulation, but also preventing the impurities sometimes found in the covering composition from rusting the boiler. Metal lath is placed against the shell, or wire lathing may be used, with spacing nipples or bars. On this lathing the blocks, or plastic covering material, are placed and secured, and a hard outer coat is then applied.

93. Loss of heat from cylindrical boilers may be prevented by arching them over with brickwork, with an air space of 1 inch between the shell and the enclosing brickwork. A more convenient and practically as effective way is to cover the boiler with dry loam to a depth of from 4 to 6 inches. This covering may readily be removed for inspection or repairs.

DAMPER REGULATORS

94. In many steam-heating installations and steam-power plants it is desirable that the steam pressure be kept practically uniform. For this purpose **damper regulators** have been designed, which, operating on a change of the steam pressure in the boiler, automatically control the position of

the damper and thus regulate the volume of gases passing into the chimney. This in turn regulates the intensity of the fire and the generation of steam.

Damper regulators may be divided into four general classes:

1. Steam-actuated regulators, where the motion of a diaphragm under variation of steam pressure is transmitted either directly or through some multiplying device to the damper.
2. Steam-actuated regulators, where a piston is subjected directly to the boiler pressure, and moving under a variation of pressure turns the damper by means of suitable connections.
3. Steam-actuated regulators, where the steam in acting on a diaphragm causes a displacement of a valve, which admits steam into a cylinder, the piston of which is connected to a damper.
4. Hydraulically-operated regulators, where the movement of a diaphragm under variation of the steam pressure operates an admission valve, admitting water under pressure to a cylinder, the piston of which is connected to the damper.

95. Damper regulators of the first class are relatively simple and inexpensive, and well adapted for low-pressure heating work, giving a regulation close enough for the purpose.

The second class of regulators is cheap and simple; it is adapted for high-pressure work, but will not give a very close regulation, owing to the fact that any variation in steam pressure sufficient to operate the device will cause the piston to move its whole length of stroke. This, in turn, causes the dampers to be either wide open or completely closed.

Regulators of the third class will regulate very closely, the makers of some such regulators guaranteeing that the motion of the damper from one direction to the other will change with a variation of steam pressure of $\frac{1}{4}$ pound per square inch, either way, from the point at which it is set to operate.

Regulators of the fourth class will also regulate very closely. Being dependent on water under pressure for their action, their application is limited to places where they can be connected either to a city water service or to a tank sufficiently high above the regulator to give the required pressure. They are sometimes connected directly to the water space of a boiler; while the damper regulator will operate when so connected, this method is open to the objection that it results in a waste of heat that may be quite large.

96. A regulator of the first class is shown in section in Fig. 51, and its application to a small heating boiler in Fig. 52. The regulator itself is composed of two bowl-shaped castings *a* and *b*, the lower one of which has a cup-like extension *c* to hold water. A soft-rubber diaphragm *d* is bolted between *a* and *b*. A stem *e* with an enlarged head

FIG. 51

rests on the diaphragm and is attached to the lever *f* having its fulcrum at *g*. A heavy weight *h* is movable along the lever, and determines, by its position, the pressure at which the device will operate. One end of the lever is connected by the chain *i* to the ash-pit damper *j*, Fig. 52, while the

other end is connected by the chain *k* to the check-damper *l*, Fig. 52. The chains are made of such a length that both dampers are just closed when the lever of the regulator is level. The bottom of the regulator is connected with the water space of the boiler by the pipe *m*. The object of connecting the regulator to the water space is to prevent steam from coming in contact with the rubber diaphragm, which would rapidly be destroyed. The steam pressure forces the water up the pipe *m* into the space below the diaphragm; the radiation of heat from the lower casting keeps this water cool, which prolongs the life of the diaphragm.

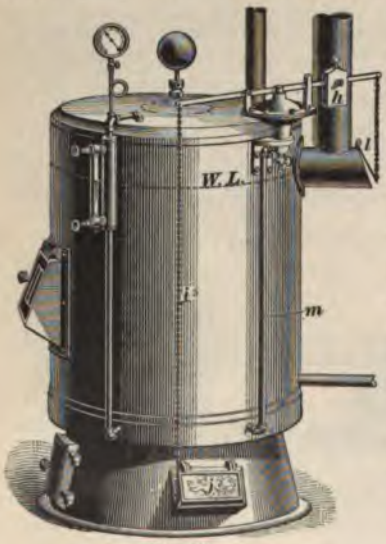


FIG. 52

The operation of the regulator is as follows: The steam pressure being transmitted to the under side of the diaphragm, bulges the latter, as shown in Fig. 51, and raises it until the downward force exerted by the weight and the tension in the rubber is equal to the upward force due to the boiler pressure. If the boiler pressure rises, the diaphragm is forced up until the downward force due to the effect of the weight and the increased tension of the rubber diaphragm balances the increased pressure. This upward motion of the diaphragm rotates the lever, which partly closes the ash-pit damper *j*. If the pressure in the boiler continues to rise, the diaphragm moves farther upwards and consequently the ash-pit damper is closed still farther, and finally the check-damper *l* is opened. If the steam pressure falls below what the damper regulator is set for, as determined by the position of the weight on the lever, the check-damper is closed and the ash-pit damper is opened.

97. Damper regulators of the class shown in Fig. 51 can be obtained with a flexible metallic diaphragm, which will greatly outlast a rubber diaphragm.

98. A regulator of the second class, known as a ***piston regulator***, is shown in Fig. 53. The cylinder *a* contains a piston that has the full steam pressure beneath it. The piston rod *b* is connected to the dampers by suitable chains and pulleys, and the pressure on the piston is balanced by the weights *d*. When the steam pressure overbalances the weights, or the reverse, the piston may travel from one end of its stroke to the other, thus opening the dampers wide or closing them entirely.

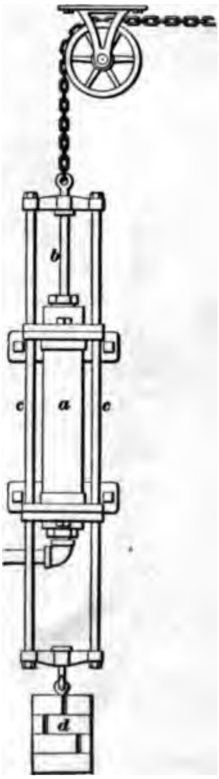


FIG. 53

99. The ***Spencer hydraulic damper regulator***, shown in Fig. 54, belongs to the fourth class. The diaphragm chamber *b* contains a flexible diaphragm dividing the chamber into two parts. The under part is filled with water that is subjected to the boiler pressure through the steam pipe *d*. The diaphragm tends to move upwards under the influence of the steam pressure, but its upward motion is resisted by the downward force exerted by the weighted lever *c*. The weights on this lever are so adjusted that it will occupy a position midway between its two extreme positions when the steam pressure in the boiler is exactly at the point at which it is to be carried. A secondary lever *f* is hinged at *f'* to the free end of *c*; this secondary lever is fulcrumed at *m*. At *g*, the valve stem of the operating valve is attached to it. This valve works inside of the piston closely fitted to the stationary cylinder *h* and serves to admit water under pressure to either side of the piston. The piston rod passes through both heads of the cylinder *h*; at its lower extremity it is connected to the

lever i pivoted at i', which, through the medium of the connecting-rod j, transmits any motion of the piston to the damper.

Let the steam pressure rise above that for which the damper is set. Then the diaphragm and the free end of the lever c move upwards. The lever f, being connected at one end at c, swings upwards around m as a fulcrum; this raises the valve inside of h and thus admits water under pressure to the bottom of the piston in h. At the same time, the valve places the upper side of the cylinder in communication with the

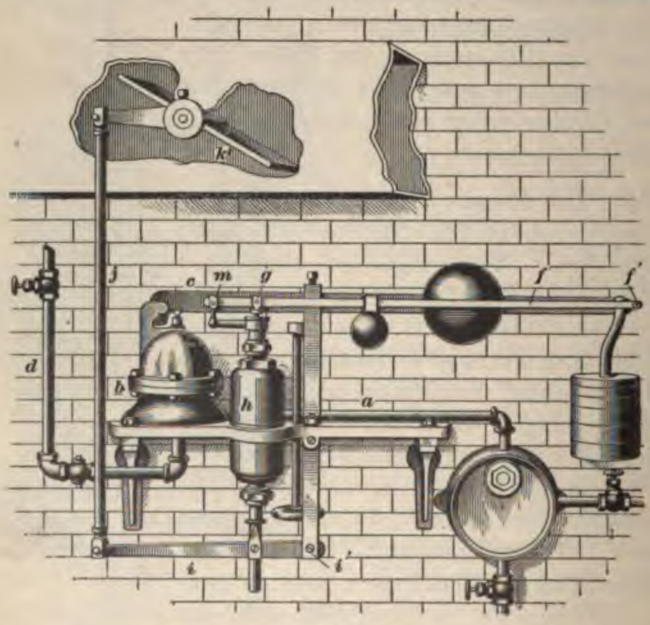


FIG. 54

water-escape pipe. In consequence thereof, the piston ascends and pulls the lever i upwards, which in turn rotates the damper k, closing it still farther. Now, as soon as the piston commences to ascend, m is moved upwards and the lever f swings around f' as a fulcrum; this causes the valve in the piston to move downwards in relation to the piston, thus closing the water-supply port and holding the piston in its new position.

When the steam pressure falls below the normal pressure, the levers *c* and *f* descend, and as *f* swings around *m*, the valve also descends, placing the upper side of the piston in communication with the water supply and the under side in communication with the water-escape pipe. Then the piston descends and the damper opens. But *f* now swings around *f'*, and thus causes the valve to ascend in relation to the piston, which is then brought to rest.

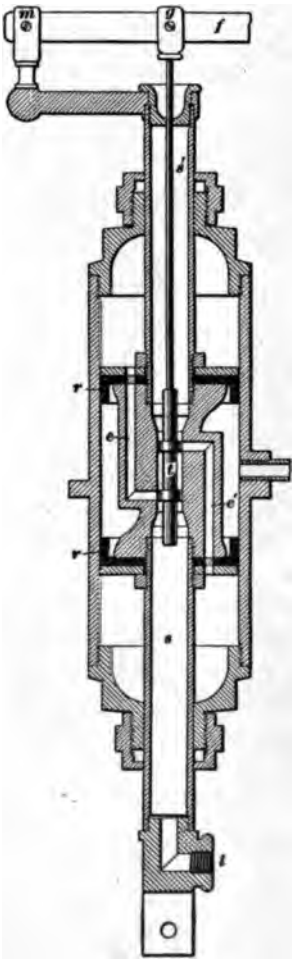


FIG. 55

100. The cylinder *h* is shown in section in Fig. 55. The piston is made water-tight by the cup-leather packing rings *r*, *r*. The water under pressure enters through the supply pipe *a* and surrounds the piston, entering through a small port into the central valve chamber and then surrounding the central port of the piston valve *t*. When the valve moves upwards, it uncovers the ports *e'* and *e*; the water under pressure flows through *e'* into the lower part of the cylinder; at the same time the water in the upper parts flows through *e* into the hollow piston rod *s* and out at *l*. The resultant motion of the piston then returns the valve to the central position shown. If the valve descends, it admits the water into the port *e* and allows the water in the lower half of the cylinder to escape through *e'* into *s'*, which, through a by-pass port not shown, communicates with *s*. The descent of the piston again returns the valve to its central position.

PRINCIPLES OF HEATING

HEAT, COMBUSTION, AND STEAM

HEAT

DEFINITIONS AND EXPLANATIONS

1. Nature of Heat.—All modern scientists and investigators agree that **heat** is a *form of energy*. It is conceived to be a motion of the molecules composing matter. All matter is composed of *molecules*, which, according to the generally accepted theory, are not in a state of rest, but are moving or vibrating back and forth with a greater or less velocity. It is this movement of the molecules that is generally believed to cause the sensations of warmth and cold; if the motion is slow, the body feels cold; whereas, if the motion is rapid, the body feels warm. Since a body in motion has kinetic energy and since the molecules composing matter are supposed to be in motion, each molecule possesses kinetic energy; hence, heat may be conceived to be a form of energy.

2. Temperature.—If a body is heated and brought near the hand, the sensation of warmth is felt; if heat is removed from this same body and it is again brought near the hand, the sensation of cold is felt. The heat that thus manifests itself is called **sensible heat**, because any change to a hotter or colder state is indicated at once by the sense of feeling, or by the aid of instruments called **thermometers**. The more sensible heat a body possesses, the hotter it is; the more sensible heat that is taken away from it, the colder it is.

The amount of sensible heat that a body may happen to possess is indicated by the word **temperature.**

The temperature is *not* a measure of the *quantity* of heat a body possesses. Temperature may be considered to be a measure of the velocity with which the molecules of a body vibrate to and fro, while the *quantity of heat* may be considered to be the total energy of the molecules composing the body. A small iron rod may be heated to whiteness and yet possess a very small quantity of heat. Its temperature is very high, but this simply indicates that the molecules of the rod are vibrating with an extremely high velocity. An iron ball 1 foot in diameter and an iron ball 1 inch in diameter may have exactly the same *temperature*, but the larger ball will have by far the greater quantity of heat.

3. The thermometer employed for measuring the usual temperatures consists of a thin glass tube, at one end of which is a bulb filled with mercury. On being heated, the mercury expands in proportion to the rise of temperature. Thermometers are graduated in different ways. In the Fahrenheit thermometer, which is the one generally used in English-speaking countries, the point where the mercury stands when the instrument is placed in melting ice is marked 32°. The point indicated by the mercury when the thermometer is placed in water boiling in the open air at the level of the sea is marked 212°. The tube between these two points is divided into 180 equal parts, called **degrees.**

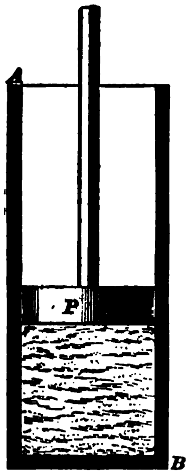


FIG. 1

4. Effects of Heat.—Consider a cylinder, Fig. 1, fitted with a piston and filled with water. If this water is, say, at the freezing point the molecules composing the water are moving to and fro with a comparatively small velocity. Place the vessel over a fire or furnace. Heat is communicated to the molecules of water, and they begin to move faster and faster; hence, their kinetic energy increases, and if a

thermometer is inserted in the vessel, it will be found that the temperature of the water rises. Consequently, one effect of heat is to raise the temperature of the body to which it is applied. But, after reaching a certain temperature, the molecules of the water not only move faster, but they move farther from each other, and their paths are longer. It is plain that if the molecules are farther apart than they were originally, the whole body of them must take up more space. In other words, after reaching a certain temperature, the water expands as heat is added. Hence, another effect of heat is to cause bodies to expand. Common examples of the expansion of bodies by heat are the lengthening of steam pipes and hot-water pipes when heated.

5. The heat supplied to the vessel of water has so far done three things: (1) It has raised the temperature of the water and thus has increased the kinetic energy of the molecules. Let the amount of heat expended for this purpose be denoted by S. (2) A certain quantity of heat has been used in expanding the water, that is, in pushing the molecules farther apart against the force of cohesion. Denote the amount of heat so expended by I. (3) Since the water expands, it must raise the piston P against the pressure of the atmosphere, and consequently more heat must be used to expand the water than would be required if there were no pressure on the upper side of the piston. Call this extra quantity of heat W.

If the total quantity of heat given to the vessel of water is denoted by Q, it will be plain that

$$Q = S + I + W$$

Ordinarily, the greater part of the heat given to a body is expended in raising its temperature, and but little is used in expanding the body. That is, the quantity S is nearly equal to the quantity Q, while the quantities I and W are extremely small.

6. Suppose that the piston in Fig. 1 is removed from the cylinder, so that the water will be in contact with the atmosphere, and that a thermometer is inserted, the experiment

being supposed to be performed at sea level at the normal atmospheric pressure of 30 inches. As the water becomes more and more heated, the temperature indicated by the thermometer will rise until it reaches 212°. So far, most of the heat has been used to raise the temperature of the water. But now, no matter how much heat is added to the water, the mercury stands at 212° and cannot be made to rise higher. This is the reason: When the temperature reaches 212°, the molecules of water have been set into such rapid motion that the force of cohesion is no longer able to hold them and they tend to separate. In other words, the water changes to a gas (steam), and all the heat is being used to effect this change. The temperature of the steam will remain at 212° until all water is changed to steam; then, if the steam is confined and more heat is applied, the temperature of the steam will begin to rise.

Take a block of ice at a temperature of, say, 14° and heat it. If a thermometer is placed in contact with the ice, the mercury will rise until it reaches 32° and will then remain stationary. As soon as this temperature is reached, the ice begins to melt, or change to water, and the heat, instead of raising the temperature farther, is used to effect this change of state. Here, then, is another effect produced by heat. It will change a solid to a liquid or a liquid to a gas. The heat that is expended in changing a body from the solid to the liquid state or from the liquid to the gaseous state is called **latent heat**, to distinguish it from sensible heat, which is that portion of the heat applied that raises temperature and therefore is indicated by the thermometer.

7. By a study of the results of applying heat to the substances that have just been considered, it is seen that the most commonly observed effects of heat are: (1) It increases the rate of motion of the molecules, an effect that is indicated by an increase in temperature. (2) It increases the lengths of the paths of, and the distance between, the molecules, thus causing the body to expand and fill a greater space. (3) It overcomes the attractive forces that tend to hold the

molecules of a substance together, and thus changes it from a solid to a liquid or from a liquid to a gas, according to the state it was in when the heat was applied.

The second statement of this summary, while generally true, is subject to exceptions, the most notable one of which is water, which in rising from a temperature of 32° Fahrenheit to a temperature of 39.2° contracts instead of expands.

8. **Unit Quantity of Heat.**—Since heat is not a substance, it cannot be measured directly in pounds or quarts; but, like force, it may be measured by the effects it produces. Suppose that a certain quantity of heat raises the temperature of 1 pound of water from 52° to 53° F.; it will take practically the same quantity of heat to raise that pound from 53° to 54°, and therefore it will take nearly double that quantity to raise the temperature of 1 pound of water from 52° to 54°. The unit quantity of heat is the quantity required to raise the temperature of a pound of water from 62° to 63°; it is called the **British thermal unit,** and is abbreviated to B. T. U.

For temperatures above 63°, it takes slightly more than 1 British thermal unit to produce a change of 1° in 1 pound of water, the difference increasing the farther the temperature is from 63°. For temperatures below 62°, it takes slightly less than 1 British thermal unit to produce a change of 1° in 1 pound of water; and, as before, the difference is greater the farther the temperature is from 62°. Thus, it will take more heat to raise the temperature of 1 pound of water from 75° to 76° than it will to raise it from 74° to 75°. Conversely, it will take less heat to raise the temperature of 1 pound of water from 42° to 43° than to raise it from 43° to 44°. However, the difference between the actual British thermal unit, as defined above, and the quantity of heat required to change the temperature of 1 pound of water 1° for any other temperature is so small that, for all ordinary purposes, it may be assumed that it takes 1 British thermal unit to produce a change of 1° F. in the temperature of 1 pound of water for all temperatures likely to be met in practice.

9. Relation Between Heat and Work.—Suppose that, in the experiment shown in Fig. 1, the piston had been allowed to remain in the cylinder while the water was being changed to steam. Steam at 212° occupies nearly 1,700 times the space that the water originally occupied; hence, the piston would be lifted in the cylinder to give room for the steam that was being formed. But, to raise the piston requires work. Here, then, is an example of work being performed by heat. On the other hand, work will produce heat. If two blocks of wood are rubbed briskly together, they will become warm, and may even ignite. The work done in overcoming friction causes the journals and bearings of fast-running machines to heat. A small iron rod may be heated to redness by pounding it on an anvil.

Since work may be changed into heat and heat into work, it seemed probable to scientists that there existed some fixed ratio between the British thermal unit and the unit of work, the foot-pound. By a series of careful experiments, Doctor Joule, of England, discovered this ratio. He found that 1 British thermal unit is equivalent to 772 foot-pounds; later and more careful experiments show that 778 foot-pounds is more nearly correct. This number, 778 foot-pounds, is called the **mechanical equivalent** of 1 British thermal unit.

The foregoing statements may be summed up as follows: Heat may be changed to work or work to heat; 778 foot-pounds of work is required to produce 1 British thermal unit; and, conversely, the expenditure of 1 British thermal unit produces 778 foot-pounds of work.

10. Specific Heat.—One British thermal unit raises the temperature of 1 pound of water 1°; will it have the same effect on a pound of mercury? Heat two 1-pound iron balls to the temperature of boiling water, 212°; having now the same weights and temperatures, each ball has the same quantity of heat. Place one of these balls in a vessel, into which slowly pour enough water having a temperature of 60° so that the iron will be cooled to 70° while the water is heated to the same temperature. Now place the other hot

ball in another vessel, into which pour mercury having a temperature of 60°, until the iron and mercury reach a common temperature of 70°. In each case the hot ball will have been cooled from 212° to 70°, and therefore each will have given up the same quantity of heat. When, however, the effects produced by the heat are considered, it is found that what has been given off by one ball has raised nearly 1.62 pounds of water 10°; that given off by the other ball, which, it will be remembered, is the same amount as in the first case, has raised 48.5 pounds of mercury (or nearly 30 times more mercury than water) the same number of degrees. It is plain, therefore, that to raise 1 pound of mercury from 62° to 63° requires one-thirtieth the heat necessary to raise 1 pound of water from 62° to 63°.

The ratio between the quantity of heat required to warm a body 1° and the quantity of heat required to warm an equal weight of water 1° is called the **specific heat** of that body. It is always expressed by giving, decimally, the value of the ratio; thus, the specific heat of mercury is $\frac{1}{30} = .0333$.

Rule I.—*To find the number of British thermal units required to raise, or to be abstracted to lower, the temperature of a body a given number of degrees, multiply the specific heat of the body by its weight, in pounds, and by the number of degrees Fahrenheit.*

Or, $$U = c\,W(t_1 - t)$$

where U = number of British thermal units;
c = specific heat;
W = weight, in pounds;
t_1 = higher temperature;
t = lower temperature.

EXAMPLE 1.—How many British thermal units are required to raise 20 pounds of lead from 50° to 400°, the specific heat of lead being .0314?

SOLUTION.—Substituting values in the formula just given,
$U = .0314 \times 20 \times (400 - 50) = 219.8$ B. T. U. Ans.

Rule II.—*To find the weight, in pounds, of a given substance that can be changed from one temperature to another by*

the application or abstraction of a certain amount of heat, divide the number of British thermal units by the product of the specific heat of the substance and the temperature difference, in degrees Fahrenheit.

Or, $$W = \frac{U}{c(t_1 - t)}$$

where the letters have the same meaning as in the formula corresponding to rule I.

EXAMPLE 2.—The specific heat of air being .2375, how many pounds of air can be raised 1° F. by 1 British thermal unit?

SOLUTION.—Substituting values in the formula,

$$W = \frac{1}{.2375 \times 1} = 4.21 \text{ lb. Ans.}$$

11. The specific heat of various substances is given in Table I, which shows that the amount of heat that would be required to raise the temperature of 1 pound of water would be sufficient to heat to an equal degree about 8 pounds of cast iron, or 30 pounds of mercury, or 4.2 pounds of air, which is about 55 cubic feet.

It appears, also, that the heat required to raise the temperature of hydrogen gas is about 3½ times as much as for an equal weight of water. The specific heats for gases given in the table are true only when the pressure remains constant.

12. Temperature and Latent Heat of Fusion and Vaporization.—In changing a solid body to a liquid, either by melting or by dissolving it, or in changing a liquid to a vapor or gas, a large amount of heat may be applied without changing the temperature. Thus, 1 pound of ice at 32° will absorb 144 British thermal units in changing to water having the same temperature. The pound of water thus produced may be heated to the boiling point, 212°, by the addition of 180.531 British thermal units. But, in order to convert the water at 212° into steam at the same temperature, 966.069 British thermal units must be added. Thus, a pound of steam at 212° contains 966.069 + 180.531 + 144 = 1,290.6 British thermal units more than 1 pound of ice at 32°, although the difference in temperature is only 180°.

The temperature at which a body changes from a solid to a liquid state is called its **temperature of fusion**; and the number of British thermal units required to effect this change in a body weighing 1 pound is called its **latent heat of fusion**. The temperature at which a body changes from a liquid state to a vapor (gas) is called its **temperature of vaporization**; and the heat required to effect this change in 1 pound of the liquid is called its **latent heat of vaporization**.

TABLE I

SPECIFIC HEAT OF SUBSTANCES

Substance	Specific Heat	Substance	Specific Heat
Air	.2375	Nitrogen	.2438
Alcohol	.7000	Oil of turpentine	.4260
Benzine	.4500	Oxygen	.2175
Brass	.0939	Platinum	.0324
Carbonic acid . .	.2170	Silver	.0570
Carbonic oxide .	.2479	Steam (superheated) . . .	.4805
Cast iron	.1298	Steel (hard) . .	.1175
Charcoal	.2410	Steel (soft) . .	.1165
Copper	.0951	Sulphur	.2026
Glass	.1937	Sulphur (melted)	.2340
Glycerine	.5550	Sulphuric acid .	.3350
Gold	.0324	Tin	.0562
Hydrogen	3.4090	Tin (melted) . .	.0637
Ice	.5040	Water at 62° . .	1.0000
Lead	.0314	Wrought iron .	.1138
Lead (melted) . .	.0402	Zinc	.0956
Mercury	.0333		

When a vapor changes back to a liquid, it is said to **condense**; and when a liquid changes back to a solid, it is said to **freeze**; in either case, an amount of heat equal to the latent heat of vaporization or of fusion, as the case may be,

must be abstracted from (given up by) the body before the change can be effected.

13. Table II shows the amounts of latent heat required for the fusion or vaporization of 1 pound of various substances, they having first been raised to the temperature at which the change takes place, and the pressure being that of the atmosphere, or 14.7 pounds per square inch.

TABLE II

HEATS OF FUSION AND VAPORIZATION

Substance	Temperature of Fusion Degrees F.	Temperature of Vaporization Degrees F.	Latent Heat of Fusion B. T. U.	Latent Heat of Vaporization B. T. U.
Water	32	212	144	966.069
Mercury	−37.8	662	5.09	157
Sulphur	228.3	824	13.26	
Tin	446		25.65	
Lead	626		9.67	
Zinc	680	1,900	50.63	493
Alcohol	−148	173		372
Oil of turpentine	14	313		124
Linseed oil		600		

The temperature of vaporization given in the table is the boiling point of the liquid under the ordinary atmospheric pressure of 14.7 pounds per square inch.

The variation of the boiling point by changes in pressure differs greatly in various liquids. The temperature of fusion, or the *melting point*, is similarly affected by changes in pressure, but the amount of the variation is unimportant for all the purposes of heating and ventilation.

EXAMPLE.—If 5 pounds of ice having a temperature of 10° below zero be mixed with hot water having a temperature of 200°, what weight of hot water will be required to melt the ice and bring the temperature of the mixture up to 60°?

SOLUTION.—The temperature of the ice is 10 + 32 = 42° below the freezing point. The amount of heat required to raise its temperature to the freezing point will be 42 × .504 (specific heat) × 5 = 105.84 B. T. U. To liquefy the ice at 32° will require 5 × 144 (latent heat of fusion) = 720 B. T. U. Then, to change the ice into water at 32°, 105.84 + 720 = 825.84 B. T. U. must be applied to it. To bring its temperature up to 60°, there must be 60 − 32 = 28° × 5 lb. = 140 B. T. U. added, which makes the total quantity of heat required, 825.84 + 140 = 965.84 B. T. U. The hot water is to be cooled from 200° down to 60°; thus, each pound will furnish 200 − 60 = 140 B. T. U. By dividing the total amount required by this quantity, it is found that 965.84 ÷ 140 = 6.9 lb. of hot water will be required. Ans.

14. Expansion of Bodies by Heat.—If a body absorbs heat, its volume, and hence its dimensions, will be changed. Nearly all substances expand when heated.

The linear expansion, or extension, of various metals and other solid substances is given, in inches per foot, for 1° rise of temperature in the following table:

TABLE III

LINEAR EXPANSION OF SUBSTANCES

Substance	Increase of Length in 1 Foot for Increase in Temperature of 1° F. Inch	Substance	Increase of Length in 1 Foot for Increase in Temperature of 1° F. Inch
Cast iron . . .	.0000740	Lead . . .	.0001900
Wrought iron .	.0000823	Tin	.0001692
Steel tubes . .	.0000719	Glass . . .	.0000550
Brass	.0001244	Brick . . .	.0000144
Copper . . .	.0001146	Firebrick . .	.0000333
Zinc	.0001961	Marble . . .	.0000566

The amount of the expansion or contraction of a bar or pipe of a given length, which will be caused by any given change in its temperature, may be found as follows:

Rule.—*Multiply the length, in feet, by the number of degrees of change in temperature. Multiply this product by the coefficient*

given in Table III for the material employed. The product will be the change in length, in inches.

Or, $$E = L(t_1 - t)c$$

where E = change in length, in inches;
L = length, in feet;
t_1 = higher temperature;
t = lower temperature;
c = coefficient taken from Table III.

EXAMPLE.—How much will a steel tube 14 feet long expand, if its temperature is raised 80°?

SOLUTION.—From Table III, the linear expansion per foot for a rise in temperature of 1° is found to be .0000719 in. for steel. Hence,

$$E = 14 \times 80 \times .0000719 = .080528 \text{ in. Ans.}$$

The expansion of wood by heat is so small that it is usually disregarded.

If metallic bodies are heated above a certain temperature, varying for different metals, and the heat is continued for any considerable length of time, the metal will become permanently elongated; that is, it will not contract to its original dimensions. The metal is then said to be *swelled*. Thus, grate bars in a furnace, or pipes that are exposed to intense heat, will increase considerably in length during long use. The strength of the metal deteriorates at the same time. Plates or other parts of furnaces that are unduly heated will swell permanently, and bulge or crack the adjoining parts.

HEAT PROPAGATION

15. Introduction.—The mode in which heat is propagated, that is, transmitted, is thus explained in Ganot's "Physics": "A hot body is one whose molecules are in a state of vibration. The higher the temperature of a body, the more rapid are these vibrations, and a diminution in temperature is but a diminished rapidity of the vibrations of the molecules. The propagation of heat through a bar is due to a gradual communication of this vibratory motion from the heated part to the rest of the bar. A good conductor is one which readily takes up and transmits the vibratory motion

from molecule to molecule, while a bad conductor is one which takes up and transmits the motion with difficulty. But even through the best of the conductors the propagation of this motion is comparatively slow. How, then, can be explained the instantaneous perception of heat when a screen is removed from a fire or when a cloud drifts from the face of the sun? In this case, the heat passes from one body to another without affecting the temperature of the medium which transmits it. In order to explain these phenomena, it is imagined that all space, the space between the planets and the stars, as well as the interstices in the hardest crystal—in short, matter of any kind—is permeated by a medium having the properties of matter of infinite tenuity, called *ether*. The molecules of a heated body, being in a state of intensely rapid vibration, communicate their motion to the ether around them, throwing it into a system of waves which travel through space and pass from one body to another with the velocity of light. When the undulations of the ether reach a given body, the motion is given up to the molecules of that body, which, in their turn, begin to vibrate; that is, the body becomes heated. This motion of the waves through the ether is termed radiation, and what is called a ray of heat is merely a series of waves moving in a given direction."

Heat may be transmitted by *radiation*, by *conduction*, and by *convection*.

16. Radiation.—The tendency of heat is to pass away from a warm body instantaneously, and with equal energy in all directions. This manner of transit is called **radiation.** Strictly speaking, all heat is radiant heat, because it invariably proceeds by radiation when it is not obstructed or retarded by the medium or material through which it passes. All known materials retard the transmission of heat to a greater or less degree. Thus, dry air permits heat to pass through it with very little obstruction, but wood offers great resistance.

The transmission of heat through a body will not affect its temperature unless the transmission is impeded to some extent. The heat that is thus intercepted may be wholly

absorbed by the body or a part of it may be reflected. The temperature of the body will be raised only by that part of the heat that is absorbed. Thus, if a sheet of clear ice is exposed to heat, a certain amount will pass through it; the greater part, however, will be absorbed, causing the ice to melt. If a person attempts to warm himself at a blazing fire, outdoors on a cold day, he may be scorched on one side by the radiant heat of the fire at the same time that he is almost frozen on the other side by the cold air that surrounds him. The air that is between him and the fire thus permits the heat to pass through it without much loss.

The law that governs the intensity of radiant heat is as follows:

Law.—*The temperature will be inversely proportional to the square of the distance from the source of heat.*

Thus, the heat that is received on a surface 1 foot square at a distance of 5 feet will diverge and cover a space of twice that width and height, having four times the area at a distance of 10 feet; the heat, being spread over four times as much surface, can have only one-fourth the intensity.

EXAMPLE.—The temperature of a certain body at a distance of 5 feet from the source is 300°; what will the temperature be at a distance of 10 feet?

SOLUTION.—Applying the law,

$$300 : x = 10^2 : 5^2, \text{ or } x = 75°. \quad \text{Ans.}$$

17. Some substances permit radiant heat to pass through them as readily as light passes through glass, while others obstruct it totally. The property of a body by virtue of which heat is enabled to pass through it is called **diathermancy.** A knowledge of the diathermic properties of metals and other substances is valuable, for means may then be devised for protecting woodwork from overheating by fire, etc. Dry air, oxygen, nitrogen, and hydrogen are almost perfectly diathermanous. A perfect vacuum also passes heat without measurable obstruction. The watery vapor that forms a part of the atmosphere greatly obstructs the passage of radiant heat, and much of the non-conducting

power that is popularly ascribed to air is really due to the vapor and dust that it contains.

The following table shows the percentage of radiant heat that will pass through the substances named:

TABLE IV

DIATHERMANCY OF SUBSTANCES

Substance	Percentage of Heat Passing Through Substance
Ordinary window glass, .07 inch thick	50 to 67
Colored window glass, .07 inch thick, violet .	45 to 53
Colored window glass, .07 inch thick, blue . .	20 to 42
Colored window glass, .07 inch thick, green .	23 to 26
Colored window glass, .07 inch thick, yellow .	40 to 44
Colored window glass, .07 inch thick, red . .	51 to 53
Rock salt, clear, 2½ inches thick	92
Pure water, layer ⅜ inch thick	11
Pure alcohol, layer ⅜ inch thick	15
Pure sulphuric acid, layer ⅜ inch thick	17
Spirits of turpentine, layer ⅜ inch thick . . .	31
Nut oil, layer ⅜ inch thick	31
Olive oil, layer ⅜ inch thick	30
Colza oil, layer ⅜ inch thick	30

The substances given in this table are supposed to be placed as a screen between the source of heat and the body to be heated, but not in contact with either. There should be a free circulation of air around the screen on both sides.

If two screens of the same substance are used, one behind the other, the second screen will pass a much larger percentage of the heat that falls on it than the first, and a third screen will, in many cases, pass nearly all the heat that passes the second screen.

18. Heat may be reflected, dispersed, or concentrated by means of mirrors or lenses, in the same manner as light.

The following table shows the reflecting power of various substances when the heat rays fall on them at an angle of 90°, the power being expressed as a percentage of the total radiant heat received:

TABLE V

REFLECTING POWER

Substance	Reflection Per Cent.	Substance	Reflection Per Cent.
Polished silver .	97	Polished zinc . .	81
Polished brass . .	93	Polished iron . .	77
Polished copper .	93	Bright tin	85
Polished steel . .	83	Glass	10

The table shows that polished silver will reflect 97 per cent. and will absorb 3 per cent. of the radiant heat falling on it. The metal will slowly become warmed by the heat absorbed. Glass reflects only 10 per cent., but, being diathermanous, a large part of the remaining 90 per cent. will pass through, and the percentage of heat that will be absorbed by it will be comparatively small. Consequently, its temperature will rise slowly.

The percentage of reflection varies somewhat with the angle at which the rays of heat impinge on the reflecting surface, becoming greater as the angle becomes less than 90°. The increase, in the case of glass, is considerable.

Heat may be concentrated by means of mirrors, if several of them are arranged to converge the reflected rays at one point. The heat of the sun has been successfully applied to the generation of steam by this means. The common burning glass is an example of the concentration of heat by means of a lens. The temperature of the concentrated rays will be equal to the total heat of the rays thus brought together.

19. Conduction.—When the transmission of heat through any certain substance requires a measurable amount of time, the manner of transmission is called **conduction.**

The distinction between radiation and conduction has regard to the rapidity of the transmission, radiation being instantaneous transmission, and conduction, retarded transmission. All known substances will conduct heat to a measurable extent, but the rapidity of the conduction varies greatly in different materials. Thus, substances are classed as *good conductors*, or *bad conductors*, according to the rapidity with which they will conduct heat.

The transmission of heat through a body may be divided into three phases: (1) The absorption of the heat at the receiving surface. (2) The conduction through the interior substance of the body. (3) The emission from the radiating surface.

All metals will conduct heat internally much faster than they can either absorb it at, or emit it from, their surfaces. It will be seen, therefore, that a knowledge of their actual conducting power is not so valuable or essential in the arts of heating and ventilation as a knowledge of their transmitting power.

The law that governs the distribution of heat by conduction is as follows:

Law.—*All bodies within a given enclosure tend to come to an equal temperature; and the heat within any particular body will tend to diffuse uniformly throughout its whole extent.*

If one or more of the bodies have a higher temperature than the others, an interchange of heat will take place until all are equally heated.

20. Table VI shows the relative conducting powers of various metals, based on that of silver, which is considered as 1.

The figures given in Table VI represent only the relative rapidity of the passage of heat from one point to another within the same body, and do not truthfully represent the capacity of the body to receive and deliver heat from or to other bodies.

When heat passes from a dense substance to a lighter one, or the reverse, the transmission is considerably retarded,

and the condition of the surface through which it passes determines the rapidity of the passage.

TABLE VI

HEAT CONDUCTIVITY OF METALS

Metal	Relative Conductivity	Metal	Relative Conductivity
Silver	1.000	Cast iron . .	.170
Copper . . .	.770	Zinc	.200
Brass	.330	Tin	.150
Steel	.120	Lead	.085

21. The rate at which heat may be absorbed at or emitted from the surface of a body depends on the nature of the material, and very largely on the condition of the surface, that is, whether it be rough, smooth, or polished. The absorptive and emissive powers of any particular substance are usually equal. A surface of freshly deposited lampblack has been found, by experiment, to be one of the best to absorb or emit heat, and is taken as a standard of comparison, being considered as 1.

The relative amount of heat absorbed or emitted by the surfaces of various substances is shown in the following table:

TABLE VII

RELATIVE HEAT ABSORPTION AND EMISSION OF SUBSTANCES

Substance	Relative Absorption and Emission	Substance	Relative Absorption and Emission
Lampblack, dry . .	1.00	Steel	.17
White lead, dry powder	1.00	Polished brass . .	.07
Paper	.98	Polished copper . .	.07
Glass	.90	Polished silver . .	.03

This table shows that the color does not affect the heat-absorbing capacity of the material, lampblack and white lead being equal in that respect.

22. **Convection.**—If there is any difference in the condition of the various layers of a body in weight, electric tension, or chemical condition, they will move about until all particles have acquired the same condition. The minute motion of each particle is called **convection,** and the general movement of the mass on itself is called **circulation.**

Convection currents are caused in many ways; thus, if a lump of sugar or of salt is partly dissolved in water, the film of water that is in contact with the lump will be denser than the surrounding water and will sink toward the bottom of the vessel. If a lump of ice is dissolved in water, convection currents will be set in motion in a similar manner, although there may be no apparent difference in temperature between them. The convection, which is caused by the application of heat to the lower layers of a liquid, is due to the expansion of these heated layers, which thus become lighter than the cold ones, and float upwards because of their buoyancy. If the heat is applied to the surface of the liquid, but little convection will occur; the motion being confined to the upper layers of the liquid, the heat will be conducted downwards through the liquid without motion, in the same manner as though it were a solid substance.

The diffusion of heat throughout a liquid may be greatly facilitated by convection if the heat is applied to the lower part of the mass, but not otherwise. Each heated particle, when in motion, comes into successive contact with great numbers of colder particles, to which its heat is conducted by actual contact. If the particles did not move, but remained stationary, as in a solid substance, or if there were no convection, the heated particle could impart its heat only to the few surrounding particles that touched it. By particle is meant a very minute portion of matter composed of a group of molecules.

Air and other gases, which are almost perfectly diathermanous, must be heated mainly by convection. The heat

may be applied with greatest effect at the bottom of the enclosure. In many cases, the heat will radiate from the hot surface and warm the opposite side of the chamber, thus increasing the extent of the heating surface and expediting the operation.

GENERATION OF HEAT

23. Strictly speaking, there is no such thing as the actual generation of heat, because heat always exists in the materials and cannot either be originated or destroyed.

The so-called generation of heat depends on the fact that many substances require much greater amounts of heat to maintain their existence separately than when two or more of them are combined. Thus, oxygen and carbon require far more heat to maintain them as separate substances than is required to maintain them when combined into carbonic acid. When fuel is burned, the oxygen and carbon unite, and only a part of their original heat is required to maintain the resultant compound; the balance is set free and warms everything in the vicinity by radiation or conduction. In a similar manner, when oxygen and hydrogen unite and form water, an enormous amount of heat is set free.

Oxygen, carbon, and hydrogen, by their combination, furnish nearly all of the heat that is available for ordinary purposes. Other combinations, notably of oxygen and silicon, produce an extremely high temperature, but they are employed for metallurgical purposes only.

All chemical or mechanical compounds either give off or absorb heat at the time the combination is effected. Thus, fresh lime and water give off considerable heat in combining; while, on the contrary, plaster of Paris and water absorb much heat in solidifying.

Other forms of energy, notably electricity and mechanical energy, can be transformed into heat; but the methods are very indirect and inefficient, and the consequent expense is so high that at present they are impracticable for ordinary heating purposes.

MEASUREMENT OF TEMPERATURE

24. Purpose of Thermometers.—The amount of sensible heat that a body may happen to possess is indicated by the term *temperature*, and by comparison with some other body having the same amount of sensible heat. Thus, a piece of iron having exactly the same amount of sensible heat as a piece of melting ice, is said to have the temperature of melting ice. If a piece of lead has the same amount of sensible heat as a kettle of boiling water, it is said to have the temperature of boiling water, etc.

FIG. 2

Owing to the imperfection of the senses, it is impossible to determine by their aid the temperature of different bodies with any degree of accuracy; hence, for this purpose, thermometers are used. In these instruments the effects of heat on bodies are made use of in obtaining the temperature, the most common method being to utilize the expansive effect of heat on liquids. Mercury and alcohol are the only liquids used—the former because it boils only at a very high temperature, and the latter because it does not solidify at the greatest known cold produced by ordinary means.

25. Thermometer Scales.—In Fig. 2 is shown a mercurial thermometer with two sets of graduations on it. The one on the left, marked *F*, is the **Fahrenheit scale,** so named after its inventor, and is the one commonly used in English-speaking countries; the one on the right, marked *C*, is the **centigrade scale,** and is used by scientists throughout the world on account of the graduations being better adapted for calculations. As will be seen, the instrument consists of a glass tube having a bulb at one end and closed at the other, so as to keep the air out. Before closing the upper end the tube is partly filled with mercury and the air above it is driven out by heating the mercury to near its boiling point, when the tube above the

mercury will be filled with mercurial vapor. It is now sealed, and on cooling, the vapor condenses and a vacuum results. The expansion or contraction of the mercury by applying or withdrawing heat from the body with which the bulb is in contact, causes the top of the mercury column to rise or fall; and, since for equal changes of temperature the mercury rises or falls equal distances, this instrument, when properly made and graduated, indicates with great accuracy any change in temperature. For the thermometer to be reliable the inside diameter should be the same throughout its length.

26. In order to graduate the thermometer, it is placed in melting ice, and the point to which the mercurial column falls is marked **freezing**. It is then placed in the steam rising from water boiling in an open vessel, and the point to which the mercurial column rises is marked **boiling**. There are now two fixed points: the freezing point and the boiling point. If it is desired to make a Fahrenheit thermometer, the distance between these two fixed points is divided into 180 equal parts, called **degrees**. The freezing point is marked 32° and the boiling point 212°; 32 parts are marked off from the freezing point downwards, and the last one is marked 0°, or zero. The graduations are carried above the boiling point and below the zero point as far as desired. This thermometer was invented in 1714, and was the first to come into general use.

In graduating a centigrade thermometer, the freezing point is marked 0°, or zero, and the boiling point 100°; the distance between the freezing and boiling points is divided into 100 equal parts; these equal divisions are carried as far below the freezing point and above the boiling point as desired. Fahrenheit placed the zero point on his thermometer 32° below freezing because that was the lowest temperature he could obtain, and he supposed that it was impossible to obtain a lower one. Where there is any doubt as to the thermometer used, the first letter of the name is placed after the degree of temperature. For example, 183° F. means 183° above zero on the Fahrenheit

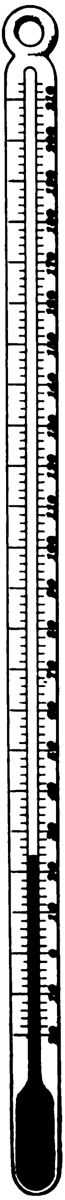


FIG. 3

instrument; 183° C. means 183° above zero on the centigrade thermometer.

27. In Russia and a few other countries, another thermometer is used, called the **Réaumur**; the freezing point is marked 0°, or zero, and the boiling point 80°, the space between these two points being divided into 80 equal parts. 183° R. means 183° above zero on the Réaumur thermometer.

Considering all civilized nations, the centigrade thermometer is most widely used; as previously stated, however, all English-speaking nations adhere, at present, to the Fahrenheit thermometer. Hence, in all technical works written in English, the Fahrenheit scale is understood whenever temperatures are given, unless distinctly stated otherwise.

In order to distinguish the temperatures below the zero point from those above, the sign of subtraction is placed before the figures, indicating the number of degrees below zero. Thus, −18° C., which is read: minus 18 degrees centigrade, means that the temperature was 18° below the zero point on the centigrade thermometer; −25.4° F. means 25.4° below zero on the Fahrenheit thermometer.

The kind of instrument shown in Fig. 2, having the graduations on a wooden or metal plate, is unsuitable for any purpose that requires accuracy. The graduations should be engraved on the glass tube, as shown in Fig. 3. All thermometers that are used for testing, or for any accurate work, are made in this way.

28. Until recently, instrument makers removed, as far as possible, the air from the thermometer tubes, and left the space above the mercury a nearly perfect vacuum. The boiling point of the mercury was lowered thereby, and, in consequence, mercurial thermometers could not be used in temperatures much exceeding 500° F. Thermometers are now made,

however, which are serviceable and accurate up to 900° F., although the ordinary boiling point of mercury is at 662°. This result is accomplished by filling the space above the mercury with gas under heavy pressure, and thereby raising the boiling point. Great care is necessary in using these instruments at high temperatures in order to avoid breakage.

29. Alcohol Thermometers.—Since mercury freezes at −37.84° F. (this corresponds to −38.8° C.) some other liquid must be had to measure temperatures below this point. For this purpose alcohol is used, as it was never frozen until very recently, and then only at an extremely low temperature obtained artificially. Since alcohol vaporizes at 173° F., the boiling point of water cannot be marked on the alcohol thermometer. The freezing point is determined in the same way as in a mercurial thermometer. To graduate an alcohol thermometer, this and a mercurial thermometer are placed in a vessel containing hot water or other liquid, and the point to which the alcohol column rises is marked. Suppose that the point to which the mercury column rises is marked 132°, then the distance between the point marked and the freezing point would be divided into 132 − 32 = 100 equal parts, and each of these parts will correspond to 1° on the mercurial thermometer. These equal divisions are then carried below the zero point as far as desired. Since alcohol boils at about 173°, alcohol thermometers should not be exposed to heat exceeding 150°.

30. Air Thermometers.—For measuring high temperatures, the **air thermometer** may be used. The construction of this instrument is shown in Fig. 4. The bulb *A* is about 1½ inches in diameter and 7 inches long, and it may be applied in any position, horizontal, or vertical, or inverted. It is connected by a tube *B* (of glass or metal, as the case may require) to a glass tube *C*. A graduated tube *D* is connected by stout rubber tubing *E* to the tube *C*, as shown. The tubes are filled with mercury up to the line *a b*. When the mercury stands at exactly equal heights in both tubes (the temperature and barometric pressure of the atmosphere

being at a standard degree), a permanent mark is made on the tube C at the level of the mercury. When the bulb is exposed to heat, the air within it will expand and will drive the mercury downwards in the tube C, and upwards in D. The latter tube should then be raised until the mercury rises in C to the mark before made. The air is thus confined to a constant volume. The difference in the level of the mercury in the tubes C and D indicates the tension or expansive force of the air confined in the bulb. The volume of air being constant, its tension is strictly proportional to the temperature. The graduations on the tube D may be made to indicate the temperature, or the pressure, or both.

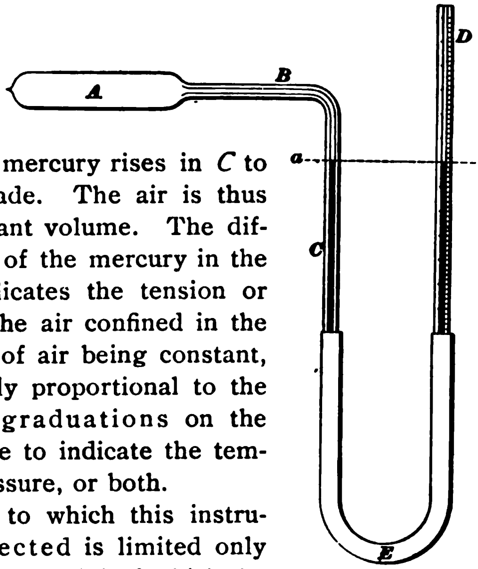


Fig. 4

The temperature to which this instrument may be subjected is limited only by the nature of the material of which the bulb is composed. The bulb may be made of iron or platinum, or of porcelain. Porcelain bulbs will serve excellently for all temperatures up to 1,200°.

31. Metallic Thermometers.—The thermometers described in the preceding articles indicate temperatures through changes in volume or pressure of fluids, induced

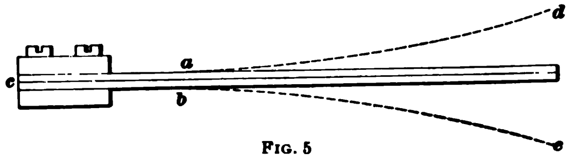


Fig. 5

by changes of heat; in so-called **metallic thermometers** temperatures are indicated through the change in shape, under heat variations, of a metallic part composed of two metals having unequal rates of expansion.

The thermometric element is usually constructed as shown in Fig. 5. Two thin strips of metal *a* and *b*, usually brass and steel, are soldered together throughout their whole length and are firmly fastened to a block *c*. If the temperature falls, the brass *a* contracts more than the steel *b*, and the compound bar bends to the curve *a d*; if the temperature rises, the brass expands most, and compels the bar to bend in the reverse direction, as shown by the curve *b e*. This thermometric element may be made of almost any shape desired, either straight or curved.

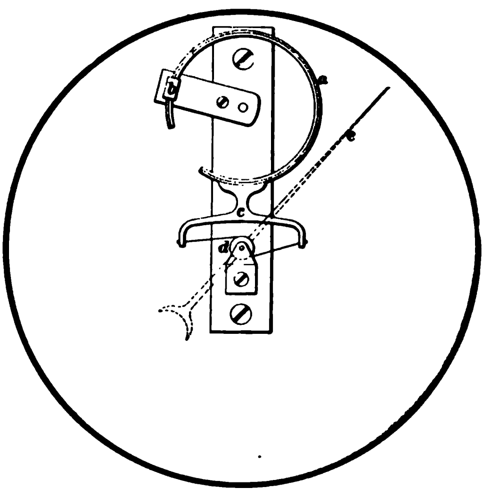


FIG. 6

Fig. 6 shows the interior mechanism of a metallic thermometer in successful use. The thermometric bar *a* is fastened to a block *b*, and a light fork *c* is soldered to its free end. The ends of the fork are connected by a fine cord that wraps around, and is secured to, the small pulley *d*. The outer end of the pulley spindle is attached to a hand, or pointer, *e*, which moves over a suitable dial. When the bar *a* expands or contracts from changes in the temperature, it changes the position of the fork *c*, and the pulley *d* with the pointer *e* is rotated correspondingly.

32. Differential Thermometers.—The instruments that have been described so far are not suitable for measuring small differences of temperature, which must frequently be made in experimental investigations and for testing purposes. An instrument of great delicacy, called the **differential thermometer**, has been devised for such uses. Its

construction is shown in Fig. 7. It consists of two bulbs *a* and *b*, connected by a horizontal tube *c*. The liquid fills the tube *c*, and rises part way up each of the vertical tubes. A small bubble of air, shown near the center of *c*, divides the liquid into two equal parts, and serves as an index to show

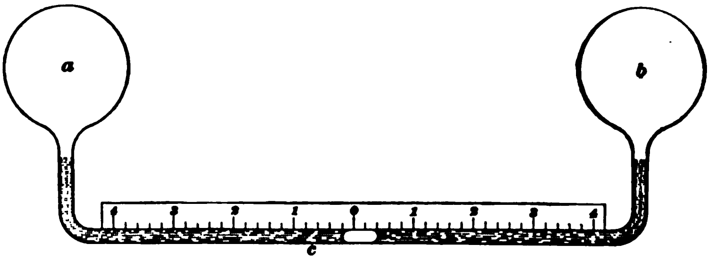


FIG. 7

the movement of the liquid. If the two bulbs are unequally heated, the difference causes the air to expand more in one bulb than the other, and so pushes the liquid toward the cooler bulb. The shifting of the bubble along the scale indicates by its position the difference in the temperature of the bulbs.

33. Maximum and Minimum Thermometers. When it is desired to know the highest and the lowest temperatures that occur within any certain period of time, instruments called *maximum thermometers* and *minimum thermometers* may be used.

The **maximum thermometer** is a mercurial thermometer having its stem laid horizontally. The best form is called **Negretti's**, after its inventor. Its construction is

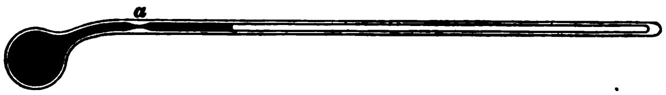


FIG. 8

shown in Fig. 8. The tube is choked close to the bulb, as at *a*, so that when the mercury is driven forwards by the rise of temperature it is retained in the tube when the mercury in the bulb subsequently contracts. The mercury

can be driven back by swinging the instrument, bulb downwards, at arm's length.

Another form of maximum thermometer is constructed with a small piece of steel wire in the tube. This wire is pushed forwards by the mercury as it expands, and is left in place when the mercury retreats. Thus, its position indicates the greatest temperature that occurred since a previous observation. The wire is gradually affected by the mercury, however, so that the instrument becomes unreliable.

34. The **minimum thermometer** has a horizontal stem, as shown in Fig. 9. The liquid used is alcohol, and the minimum temperature is indicated by the position of a small float that is enclosed within the tube. When the

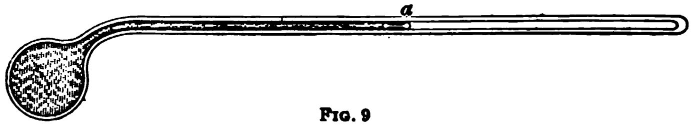


FIG. 9

alcohol contracts, the float will follow the retreating liquid; but when it expands, the liquid will flow past the float, thus leaving it at the point of lowest temperature. In reading the indication of the instrument, the position of the forward end of the float is noted, as at *a*.

As alcohol is vaporized at moderate heat, this thermometer should not be exposed to the direct rays of a bright sun, but should be shaded. Frequently, maximum and minimum thermometers are mounted together on a single stand, for more convenient use.

35. Recording Thermometers.—When it is desired to have a continuous record of the changes of temperature at any certain point, the object may be attained by means of instruments called **thermographs**, or recording thermometers.

The **Draper recording thermometer**, shown in Fig. 10, records the temperature on a paper chart attached to a revolving dial *d*. As the temperature changes, the pen *a*, which is charged with ink, is moved toward or from the center of the dial by means of a metallic thermometer that

is enclosed within the case. It traces a line on the chart as the dial turns, and the position of this line with reference to the lines that are printed on the paper clearly indicates the temperature that existed at any time during the period

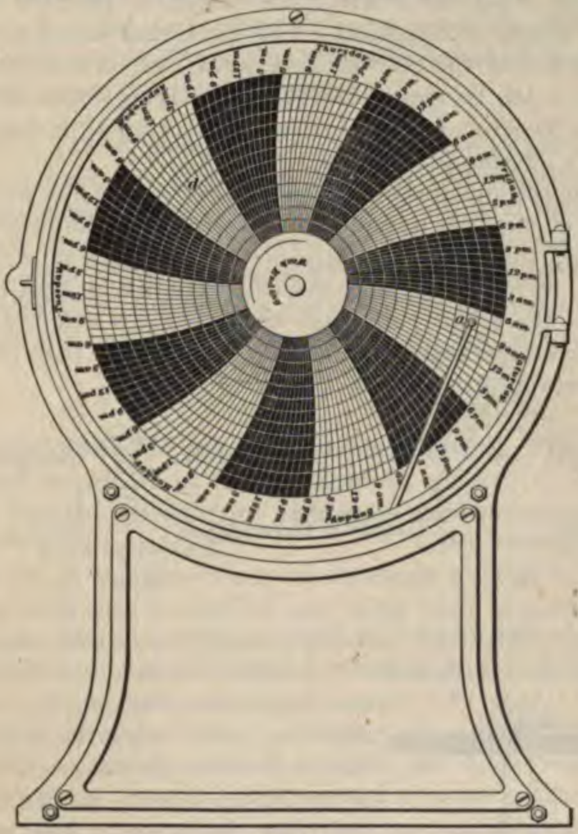


FIG. 10

included by the chart. The dial is revolved by suitable clockwork, and makes one revolution in a day or week, as desired. The paper charts are removed daily or weekly, and can be filed away for future reference.

36. Use and Care of Thermometers.—All thermometers should be very carefully handled, because they are

easily broken. Much annoyance and vexation may be avoided by always keeping the instruments in their cases when not in actual use.

Before using a mercurial thermometer, make sure that it is clean. Find out whether the thread of mercury in the tube is parted or displaced. The force that draws the mercury back into the bulb is quite weak, and if the column is parted, it can be restored to proper working order by holding it in the hand, bulb downwards, and swinging it vertically at arm's length, a few times.

In measuring atmospheric temperature, the thermometer should be exposed to unobstructed circulation, and should be protected from the direct rays of the sun and from radiation from all warm bodies in its vicinity. It must be kept strictly dry. If there is any moisture on the bulb, it will evaporate and cause the mercury to fall to a lower point than the true temperature of the air.

37. To ascertain the temperature of steam, water, or air that is passing through a pipe, it should be provided with **thermometer cups** that are properly adapted to the situation.

Fig. 11 shows a thermometer cup of ordinary construction. The stem *a* is made quite thin, $\frac{1}{16}$ inch or less, and the central hole should be just large enough to readily admit the bulb of the thermometer. A bore of $\frac{1}{2}$ inch is sufficient for the largest thermometer that will be required, and $\frac{3}{8}$ inch is large enough for all ordinary purposes. The cup is partly filled with mercury into which the thermometer bulb is sunk; this mercury is a good medium for conducting heat from the cup to the thermometer bulb. The neck *b* of the cup is provided with a tapering screw thread, corresponding to a standard pipe plug, and the collar *c* is made hexagonal, to fit an ordinary wrench. The cup should be made of iron; if it is made of brass, it cannot be used with mercury without

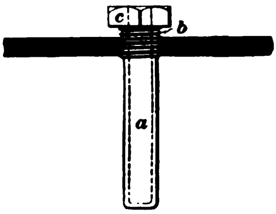


FIG. 11

damage to the brass. The depth of the cup should be sufficient in all cases to contain the entire bulb of the thermometer within that part of the stem that is actually surrounded by the hot fluid to be tested. The cups should stand vertically, or as nearly so as circumstances will permit. The end of the stem should always extend at least to the center of any pipe to which it may be attached, and it may extend as much farther as desired.

38. Thermometer cups are usually left in place as permanent fixtures. If the cups are made of brass, they should be partly filled with heavy engine oil of good quality, and should be allowed to become hot before the thermometer is inserted. The thermometer should be allowed several minutes' time in which to attain its maximum temperature before any readings are taken. The projecting stem of the

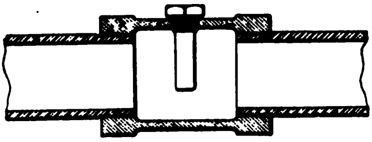


FIG. 12

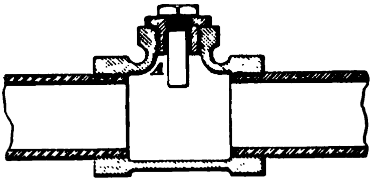


FIG. 13

thermometer should be guarded against currents of air, hot or cold, which might influence the indications of the instrument. In locating thermometer cups, care should be taken to avoid all places where air might collect around the stem, and also any pockets that might be filled with partly cooled fluid. An air bubble around the stem of the cup will materially reduce the indication of the thermometer.

39. If the cup is inserted in a T or other fitting, it should be inserted through the side, as in Fig. 12, and should not be put in as shown in Fig. 13, because of the liability of air lodging at *A*. Fig. 14 shows the proper method of inserting a cup at a vertical elbow. The stem is long enough to bring the bulb of the thermometer well below any possible

collection of air at A. The cup is located a little forward of the center of the vertical pipe, so as to be in the middle of the current.

When cups cannot be used, the temperature of a hot surface may be found by laying the thermometer against it, and covering the instrument with felt or other good non-conducting material. Only enough of the stem should be exposed to allow the indications to be readily observed. This method will not secure accurate results, and is not to be recommended for any purpose requiring accuracy. The thermometer will show the temperature of the pipe only, which may, or may not, agree with the temperature of the liquid within it.

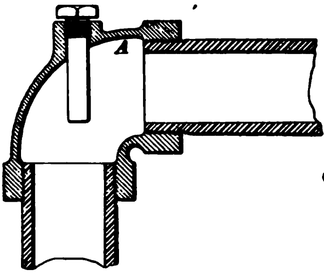


FIG. 14

40. Pyrometers.—Instruments that are designed especially to register very high temperatures, such as exist in ovens, chimney flues, furnaces, etc., are called **pyrometers**. The pyrometers in common use are modifications of the metallic thermometer; a widely used form is shown in Fig. 15.

The casing, or tube, a, is made of some metal that will endure the heat and withstand corrosion. The expanding elements are contained within the tube a and consist of a tube of iron and a central rod of copper, which are united at the end near the cap b. The difference in the expansion of the two metals is utilized, by mechanism very similar to that in a steam gauge, to move the index hand over the graduated dial c.

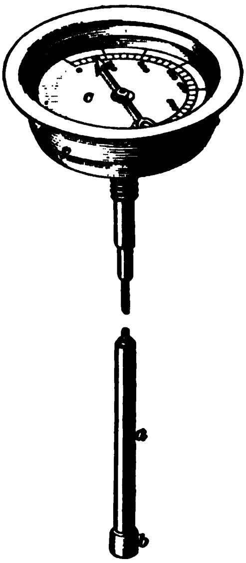


FIG. 15

These instruments are used by inserting the stem into the

flue through which hot gases are passing, and are usually left in place for permanent use.

In using the instrument, no readings should be taken until it has had time to become thoroughly heated through. The hole through which the stem of the instrument is inserted must be guarded against the entrance of cold air or the outflow of burning gas against the dial case.

ABSOLUTE TEMPERATURE

41. It has been found, by experiment, that all perfect gases will expand $\frac{1}{460}$ of their volume when heated at a constant pressure from zero to 1° above it. It is inferred, therefore, that the ultimate limit of contraction will be found at 460° below zero on the Fahrenheit scale, and that at this point all motion of the molecules ceases. This point is called the **absolute zero** of temperature; temperatures measured from absolute zero are called **absolute temperatures.** Ordinary thermometers are not graduated to read directly to absolute temperatures; with a Fahrenheit thermometer 460°, and with a centigrade thermometer 273⅓°, must be added to the reading of the thermometer to obtain the absolute temperature for thermometer readings above zero. If the thermometer registers below zero, the number of degrees registered below zero must be subtracted from 460° or 273⅓°, according to whether the Fahrenheit or centigrade thermometer is used.

For example, a temperature of 85° by the Fahrenheit thermometer corresponds to $85 + 460 = 545°$ absolute, and a temperature of $-3°$ corresponds to $460 - 3 = 457°$ absolute. Likewise, a temperature of 40° centigrade corresponds to $40 + 273\frac{1}{3} = 313\frac{1}{3}°$ absolute, and a temperature of $-12°$ centigrade corresponds to $273\frac{1}{3} - 12 = 261\frac{1}{3}°$ absolute.

When a temperature is mentioned, it is usually understood that the temperature indicated by the thermometer is meant; it is the universal practice to add "absolute" to the number of degrees whenever it is desired to convey the information that absolute temperature is meant.

In sanitary engineering, absolute temperatures enter chiefly into calculations relating to changes in volume or weight of gases under changes of temperature.

EXAMPLES FOR PRACTICE

1. How many British thermal units are given off by 42 pounds of tin in cooling from 318° to 62° F.? Ans. 604.27 B. T. U.

2. How many British thermal units will be required to melt 10 pounds of lead from an original temperature of 70°? Ans. 1,842.5 B. T. U.

3. A wrought-iron pipe line 350 feet long is raised in temperature from 60° to 300° when steam is turned into it. How much will it lengthen? Ans. 6.9 in.

4. If the temperature within 1 foot of a piece of hot iron is 2,500° F., what will it be at a distance of 5 feet? Ans. 100° F.

5. What is the absolute temperature corresponding to −21° F.? Ans. 439°

COMBUSTION

LAWS OF CHEMICAL COMBINATIONS

42. Elements and Compounds.—Every body, every mass of matter is either an *element*, a *compound*, or a *mixture*. Iron, silver, sulphur, and oxygen are elements; water, wood, lime, and carbonic acid are compounds.

A compound may be decomposed or divided into separate substances. For example, if an electric current is passed through water, the water slowly disappears and two gases are formed. These gases are entirely unlike and neither resembles the water from which it is produced. Likewise, lime can be divided into two other substances—calcium and oxygen. Any substance that can thus be decomposed or divided into other substances is called a **compound.**

There are substances that have never been decomposed into other substances. By no known process can sulphur be separated into other substances; likewise, iron, gold, arsenic, and many other substances. Substances that have never been decomposed or called **elements.**

In referring to an element it is customary to simply use the symbol, which is usually the first letter of the name. Thus, *H* stands for hydrogen, *C* for carbon, etc.

The elements that will be considered are: Hydrogen, *H*; oxygen, *O*; nitrogen, *N*; carbon, *C*; sulphur, *S*.

43. Chemical Combination.—When two or more elements are brought into contact under favorable circumstances, they will combine and form a substance that is unlike either of the elements; of course, the new substance will be a compound. Thus, if carbon and oxygen are brought together at a high temperature, they will combine and form carbon dioxide. Hydrogen and oxygen combine to form water. Hydrogen, nitrogen, and oxygen, when combined in certain proportions, form nitric acid. A given volume of nitrogen and three times that volume of hydrogen combine and form ammonia—a gas that differs greatly from both nitrogen and hydrogen.

It is supposed that each molecule of an element, such as hydrogen or oxygen, is composed of 2 atoms. It is further supposed, by chemists, that at a given pressure and temperature equal volumes of all gases, whether simple or compound, contain the same number of molecules. Thus, a cubic foot of hydrogen, a cubic foot of air, a cubic foot of steam, all contain the same number of molecules at the same temperature and pressure.

Suppose that a cubic foot of hydrogen gas is allowed to come in contact with a cubic foot of chlorine gas (symbol, *Cl*). The mixture is exposed to heat or light and the gases combine. The process of combination is explained as follows: There is a certain attraction, or affinity, between the hydrogen atoms and the chlorine atoms. Under the influence of heat or light this attraction becomes so strong that the 2 atoms composing the molecule of hydrogen are torn apart. Likewise, the atoms composing a molecule of chlorine separate. Each atom of chlorine seizes on an atom of hydrogen and forms a molecule of an entirely new gas; viz., hydrochloric-acid gas. Since each atom of chlorine takes 1 atom

of hydrogen, it is plain that the number of molecules of each gas must be the same. In other words, 1 cubic foot of chlorine requires 1 cubic foot of hydrogen to combine with it; these gases cannot be made to combine in any other proportion. For example, if 3 cubic feet of chlorine is placed in contact with 2 cubic feet of hydrogen, 4 cubic feet of hydrochloric-acid gas will be formed, and the extra cubic foot of chlorine would still remain chlorine. The symbol for hydrochloric-acid gas is HCl.

Suppose that hydrogen and oxygen are placed in contact and heated. They will combine and form steam (or water); but it will be found that each atom of oxygen seizes 2 atoms of hydrogen to form a molecule of water, and therefore the volume of hydrogen must be double the volume of the oxygen with which it combines. This is shown by the symbol for water, which is H_2O; that is, a molecule of water is composed of 2 atoms of hydrogen to 1 of oxygen. Similarly, the symbol for ammonia is NH_3; that is, 3 atoms of hydrogen to 1 of nitrogen. Again, hydrogen and carbon form a compound; each atom of carbon seizes 4 atoms of hydrogen and forms a molecule of marsh gas. The symbol for marsh gas is, therefore, CH_4.

44. The symbol of any compound indicates how the atoms of the elements combine to form the compound. Thus, the symbol for water, H_2O, shows that 2 atoms of hydrogen and 1 of oxygen unite to form a molecule of water. The symbol H_2SO_4 (sulphuric acid) shows that 1 molecule of the sulphuric acid contains 2 atoms of hydrogen, 1 of sulphur, and 4 of oxygen.

45. Combination by Weight.—One cubic foot of hydrogen combines with just 1 cubic foot of chlorine. But on weighing each gas it is found that the cubic foot of chlorine weighs 35.5 times as much as the cubic foot of hydrogen. A cubic foot of oxygen weighs 16 times as much as a cubic foot of hydrogen.

At a given pressure and temperature equal volumes of gases contain the same number of molecules. Therefore,

1 cubic foot of oxygen must contain the same number of atoms as 1 cubic foot of hydrogen. Now, since the former weighs 16 times as much as the latter, it follows that an atom of oxygen weighs 16 times as much as an atom of hydrogen. Similarly, an atom of chlorine weighs 35.5 times as much as an atom of hydrogen. This ratio between the weight of an atom of any element and the weight of an atom of hydrogen is called the **atomic weight** of the element. The atomic weight of any element may be found by dividing the weight of a given volume, say 1 cubic foot of the element when in a gaseous state, by the weight of 1 cubic foot of hydrogen when both are at the same temperature and pressure. The atomic weight is, therefore, much the same thing as specific gravity, except that the weight of hydrogen is used as the standard of comparison instead of the weight of water.

The atomic weights of the elements named are: Hydrogen, H, 1; oxygen, O, 16; nitrogen, N, 14; carbon, C, 12; sulphur, S, 32. By the aid of these atomic weights, the composition of any substance, by weight, called its **molecular weight,** can be found when its symbol is known. The molecular weight may be defined as the ratio of the weight of a molecule of a substance to the weight of an atom of hydrogen, the weight of the latter being taken as 1.

Take water, symbol H_2O; that is, there are 2 atoms of H to 1 of O. Multiply the number of atoms of each by the atomic weight of the atom. Thus,

$$\begin{array}{rl} 2 \times 1 = & 2 \text{ parts by weight of hydrogen} \\ 1 \times 16 = & \underline{16} \text{ parts by weight of oxygen} \\ & 18 \text{ parts by weight of water} \end{array}$$

Hence, the water is composed of $\frac{2}{18} = .1111 = 11.11$ per cent. of hydrogen and $\frac{16}{18} = .8889 = 88.89$ per cent. of oxygen.

As another example, take carbon dioxide, CO_2. Then,

$$\begin{array}{rl} 1 \text{ atom of } C \times \text{atomic weight, } 12 = & 12 \text{ parts by weight of } C \\ 2 \text{ atoms of } O \times \text{atomic weight, } 16 = & \underline{32} \text{ parts by weight of } O \\ & 44 \text{ parts by weight of } CO_2 \end{array}$$

Hence, CO_2 contains $\frac{12}{44} = .2727 = 27.27$ per cent. carbon, and $\frac{32}{44} = .7273 = 72.73$ per cent. oxygen. These examples show that the molecular weight of water is 18 and of carbon dioxide 44.

46. Mixtures.—Two or more substances, either elements or compounds, may be mixed together and yet not combine to form a new substance. They are then said to form a **mixture.** The mixture has the properties of the substances composing it. The most familiar example of a mixture is ordinary air. It is composed of oxygen and nitrogen, 23 parts by weight of the former to 77 parts by weight of the latter. The two gases are not combined chemically; they are simply mixed.

ELEMENTS OF COMBUSTION

47. Definitions.—**Combustion** is a very rapid chemical combination. The atoms of some of the elements have a very great affinity, or attraction, for those of other elements, and when they combine they rush together with such rapidity and force that heat and light are produced. Oxygen, for example, has a great attraction for nearly all other elements. An atom of oxygen is ready to combine with almost any substance with which it comes in contact. For carbon, oxygen has a particular liking, and whenever these elements come in contact at a sufficiently high temperature, they combine with great rapidity. The combustion of coal in the furnace of a boiler is of this nature. The temperature of the furnace is raised by kindling the fire, and then the carbon of the coal begins to combine with oxygen taken from the air. The combination is so rapid and violent that a great quantity of heat is given out.

The elements that enter into combustion are oxygen, and usually either carbon or hydrogen. Coal, wood, and other fuels are composed almost entirely of these three elements. Combustion is, therefore, a rapid chemical combination of oxygen with either carbon or hydrogen, or both.

48. When carbon and oxygen combine they form CO_2, or carbon dioxide; when hydrogen and oxygen combine they form water, H_2O; these are called the **products of combustion.** When, as is ordinarily the case, the oxygen is obtained from the air, the nitrogen of the air passes into the furnace with the oxygen. It takes no part in the combustion, but passes through the furnace and up the chimney with the CO_2 without any change in its nature; it is, however, usually called a product of combustion in air.

49. Weight and Volume of Air Required for Combustion.—Carbon dioxide, CO_2, is composed by weight of 12 parts of carbon and 32 parts of oxygen. Hence, to burn a pound of carbon requires $\frac{32}{12} = 2\frac{2}{3}$ pounds of oxygen. If the oxygen is taken from the air, which contains only 23 per cent. of oxygen, it will take $2\frac{2}{3} \div .23 = 11.6$ pounds of air to supply the $2\frac{2}{3}$ pounds of oxygen. The combustion of a pound of carbon may be represented as follows:

	Elements	Products
1 pound carbon .	1 pound carbon . .	3.67 pounds CO_2
11.6 pounds air . . .	2.67 pounds oxygen . .	
	8.93 pounds nitrogen .	8.93 pounds nitrogen
12.6	12.6	12.6

That is, 1 pound of carbon requires 11.6 pounds of air for complete combustion. Of this air, 2.67 pounds is oxygen, which combines with the pound of carbon, forming 3.67 pounds of carbon dioxide. The 8.93 pounds of nitrogen contained in the air passes off with the CO_2 as a product of combustion.

Take, next, the complete combustion of 1 pound of hydrogen. The product of the combustion is water, H_2O, which is composed, by weight, of 2 parts of hydrogen to 16 parts of oxygen. Hence, 1 pound of H requires $\frac{16}{2} = 8$ pounds of O to unite with it. The air required to furnish 8 pounds of O is $8 \div .23 = 34.8$ pounds. The process of combustion is, therefore, as follows:

	Elements	Products
1 pound hydrogen	1 pound hydrogen	9 pounds water (H_2O)
34.8 pounds air . .	8 pounds oxygen	
	26.8 pounds nitrogen	26.8 pounds nitrogen
35.8	35.8	35.8

50. There is one other case that may occur; the combustion of carbon may not be complete. If insufficient air or oxygen is supplied to the burning carbon, it is possible for the carbon and oxygen to form another gas, carbon monoxide, or CO, instead of carbon dioxide, CO_2.

The combustion of 1 pound of carbon to form CO, of course, requires only one-half the oxygen that would be necessary to form CO_2. This is because in CO gas 1 atom of carbon seizes 1 atom of oxygen instead of 2 atoms. To burn 1 pound of carbon to CO_2 requires 11.6 pounds of air. To burn it to CO would, therefore, require but 5.8 pounds of air.

51. The quantities of air required for combustion are shown in the following scheme:

		Product of Combustion 1 Pound Air at 62°
Hydrogen	34.8 pounds, or 457 cubic feet	Water Nitrogen
Carbon burned to CO_2	11.6 pounds, or 152 cubic feet	Carbon dioxide Nitrogen
Carbon burned to CO	5.8 pounds, or 76 cubic feet	Carbon monoxide Nitrogen

52. The fuels in common use are composed chiefly of carbon with sometimes a small percentage of hydrogen, oxygen, and incombustible matter, called *ash*. When the percentages of carbon and hydrogen are known, the air required for the combustion of 1 pound of the fuel is easily found. For example, suppose that a certain coal has 91 per cent. carbon and 9 per cent. hydrogen. To burn the carbon requires $152 \times .91 = 138.32$ cubic feet of air; to burn the hydrogen requires $457 \times .09 = 41.13$ cubic feet of air. Hence, to burn 1 pound of the fuel requires $138.32 + 41.13 = 179.45$ cubic feet of ai·

From this, the following rule is derived:

Rule.—*To find, in cubic feet, the quantity of air at 62° F. required to burn 1 pound of a given fuel, multiply the percentage of carbon by 152, and the percentage of hydrogen by 457; add the two products.*

Or, $$A = 152\,C + 457\,H$$

where A = air, in cubic feet;
C = percentage of carbon, expressed decimally;
H = percentage of hydrogen, expressed decimally.

EXAMPLE 1.—How many cubic feet of air are required to burn 1 pound of coal containing 84 per cent. carbon, 5 per cent. hydrogen, 7 per cent. oxygen, and 4 per cent. ash?

SOLUTION.—Applying the formula,
$A = 152 \times .84 + 457 \times .05 = 150.53$ cu. ft. Ans.

EXAMPLE 2.—How many cubic feet of air are required to burn 1 pound of coal oil containing 88 per cent. carbon, 11 per cent. hydrogen, and 1 per cent. oxygen?

SOLUTION.—Applying the formula,
$A = 152 \times .88 + 457 \times .11 = 184.03$ cu. ft. Ans.

When the fuel already contains oxygen, a little less air than is given by the rule is required to burn it; if it contains sulphur, a little more air will be required than is given by the above rule. In either case the difference is very slight. It will be found that 1 pound of coal requires practically the same amount of air, whether it be anthracite or bituminous. Roughly speaking, it requires about 12 pounds, or 160 cubic feet, of air to burn 1 pound of carbon or coal. If less air is supplied, the combustion is imperfect; that is, the carbon burns to CO instead of CO_2.

53. Rapidity of Combustion.—The process by which oxygen combines with other substances is designated by the general term **oxidation**. This process proceeds with varying degrees of rapidity, according to circumstances. Slow oxidation is sometimes described as **slow combustion**, but the term *combustion* is generally understood to mean rapid oxidation, which causes the material to glow with light

and heat, or which produces flame. The temperature at which combustion begins is called the **point of ignition.**

The term **spontaneous combustion** is applied to those cases in which ignition takes place without the external application of heat. It may occur in several ways. Thus, when a combustible body is slowly oxidized and the heat evolved is prevented from escaping, the temperature of the body will gradually rise, the oxidation will increase in rapidity, and the evolution of heat will proceed faster, until finally the temperature reaches the point of ignition, when the body takes fire and burns. This is liable to occur in a mass of oily cotton waste, or in a pile of closely packed hay or straw that is slightly moist. Large heaps of coal refuse, or culm, frequently take fire from this cause, especially if the refuse contains much sulphur.

Spontaneous ignition is also caused by rapid absorption of oxygen from the air. Thus, freshly made charcoal is destitute of oxygen, and when it is exposed to the air, it will absorb oxygen so rapidly that it is very liable to take fire. This may be prevented by moistening the charcoal with water.

A pipe containing steam at ordinary pressure will cause spontaneous ignition of wood that is very close to it, or in contact with it. As the moisture is driven out of the wood by the heat, oxygen from the air takes its place, and the woody substance becomes oxidized to a certain extent. The change in the wood is increased by each repetition of the process, or by steadily applied heat; and the wood becomes brown in color, then begins to char, and finally, when the heat is unusually high or the change from cold to hot is unusually quick, it may ignite and burst into flame.

54. In burning coal and similar substances, the carbon must be heated to incandescence before the oxygen can combine with it with sufficient rapidity to maintain the fire. The heat developed is partly lost by radiation, and the remainder is spent in warming the oxygen consumed and the nitrogen that accompanies it, and in raising the temperature of the carbon to incandescence. This latter requirement is the one

of combustion of a pound of this fuel is found thus: The heat of combustion of the carbon is $14,600 \times .85 = 12,410$ British thermal units. The heat of combustion of the hydrogen, remembering that the oxygen present combines with one-eighth of its weight of hydrogen, is $62,000 \times \left(.06 - \frac{.04}{8}\right) = 3,410$ British thermal units. The heat of combustion of the sulphur is $4,000 \times .01 = 40$ British thermal units. Then, the total heat of combustion is $12,410 + 3,410 + 40 = 15,860$ British thermal units. Expressing this in the form of a rule, Dulong's rule is obtained, which is as follows:

Rule.—*To find the heat of combustion of a pound of a given fuel, multiply 14,600 by the percentage of carbon. Divide the percentage of oxygen by 8, subtract the quotient from the percentage of hydrogen, and multiply 62,000 by the remainder. Multiply 4,000 by the percentage of sulphur, and add the three products.*

Or, $$X = 14,600\,C + 62,000 \times \left(H - \frac{O}{8}\right) + 4,000\,S$$

where X = heat of combustion per pound in British thermal units;
C = percentage of carbon, expressed decimally;
H = percentage of hydrogen, expressed decimally;
O = percentage of oxygen, expressed decimally;
S = percentage of sulphur, expressed decimally.

EXAMPLE.—What is the heat of combustion of a pound of fuel containing 66 per cent. carbon, 8 per cent. oxygen, 8 per cent. hydrogen, 2 per cent. sulphur, and 16 per cent. ash?

SOLUTION.—Applying the formula,

$$X = 14,600 \times .66 + 62,000 \times \left(.08 - \frac{.08}{8}\right) + 4,000 \times .02$$
$$= 14,056 \text{ B. T. U. Ans.}$$

56. Temperature of Combustion.—Making no allowance for losses of heat and supposing that just enough air is furnished for the combustion, burning carbon should have a temperature about 4,940° F. above zero; burning hydrogen should have a temperature of about 5,800° F. above zero. In practice, these temperatures are never attained on account of the losses of heat. Usually, the quantity of air admitted

that usually determines the rate of combustion. In burning light oils, the amount of heat consumed in raising their temperature to the point of ignition is very small; consequently, they burn with great rapidity. But, in the case of hard coal, the amount of heat thus consumed is relatively large, and the combustion, therefore, proceeds slowly. If the loss of heat by radiation be diminished, then the amount available for heating the fuel will be greater, and the combustion will be intensified.

Combustion proceeds only at the surface of a lump of coal, although the interior of the lump may be incandescent. This is because the oxygen necessary for combustion can be obtained only on the outer surfaces, where the fuel is in contact with the air.

Combustion is not instantaneous in any case, because a measurable amount of time is always required to elevate the temperature of the materials to the point of ignition; the phenomenon known as an **explosion** differs from ordinary combustion mainly in the amount of time occupied by the process of combination.

55. Heat of Combustion.—The quantity of heat developed by the complete combustion of a pound of fuel is known as its **heat of combustion**, and also as its *heating value*, *heating power*, *calorific value*, or *calorific power*. The quantities of heat produced by the complete combustion of the elements composing the fuels have been found by experiment. They are: Hydrogen, 62,000 British thermal units per pound; carbon burned to carbon dioxide, CO_2, 14,600 British thermal units per pound; carbon burned to carbon monoxide, CO, 4,400 British thermal units per pound; sulphur, 4,000 British thermal units per pound.

When a fuel contains oxygen, the oxygen during combustion will unite with one-eighth its weight of hydrogen and form water, H_2O, thus reducing the heat of combustion of the hydrogen. Suppose that a fuel contains by weight 85 per cent. carbon, 4 per cent. oxygen, 6 per cent. hydrogen, 1 per cent. sulphur, and 4 per cent. ash. The total heat

to the furnace is from 50 to 100 per cent. more than is theoretically necessary for the combustion. This extra quantity of air enters at a temperature of 60° or 70°, and escapes up the chimney at a temperature of from 400° F. to 600° F. A large quantity of heat is thus wasted and the temperature of the fire is greatly lowered. Where the fire is outside the boiler and the furnace is surrounded by brickwork, the furnace temperature may be 2,500° F. or 3,000° F.; but when the furnace is inside the boiler and is surrounded on all sides by water, the temperature rarely rises above 2,000° F. and is usually less. A high temperature is desirable, since the water of the boiler will take up heat much faster at high furnace temperatures than at low furnace temperatures; combustion is also more perfect at high temperatures.

57. Maximum Evaporation of Water.—It requires 966.1 British thermal units to evaporate 1 pound of water at 212° F. into steam of the same temperature and corresponding pressure. Then, the greatest weight of water, that is, the theoretical weight, that can be evaporated from and at 212° F. by a pound of a given fuel is found by dividing its heat of combustion per pound by 966.1.

EXAMPLE.—How many pounds of water can be evaporated, theoretically, by a pound of coal whose heat of combustion is 13,897 British thermal units?

SOLUTION.—Evaporation $= \frac{13{,}897}{966.1} = 14.38$ lb. Ans.

58. Smoke.—All kinds of coal contain more or less volatile matter, which is given off before actual combustion begins. The amount given off by anthracite is so small that it usually escapes notice, but in bituminous coal the volatile matter constitutes from 15 to 30 per cent. of the total weight. This volatile matter largely consists of carbon compounds, which are distilled off at a temperature lower than that at which the fixed carbon of the coal ignites. If these volatile constituents of coal, which are known as **hydrocarbons** and consist chiefly of combinations of carbon and hydrogen, are not ignited and burned completely as fast as they are distilled off, there will be a serious loss of heat, and incidentally

a dense, black smoke will be formed. The coloring matter giving to smoke its peculiar color is carbon in a finely divided state; this carbon, combined with tarry vapors distilled off during the combustion of coal and condensed afterwards, forms the soft, sticky dust known as **soot**. This soot deposits on all surfaces it comes in contact with; being a very poor conductor of heat it greatly retards the transmission of heat to the water inside of steam boilers. The formation of black smoke, even in large volumes, is not necessarily an indication of a very poor combustion, since a very small amount of carbon mixed with a large volume of gases of combustion will give them a dense black color. On the other hand, incomplete combustion and the formation of black smoke often exist at the same time.

The complete combustion of the hydrocarbons, and incidentally a prevention of smoke, can be insured only by a very high furnace temperature and an adequate air supply intimately mixed with the gases as soon as they are distilled off.

EXAMPLES FOR PRACTICE

1. How many pounds of air will be required for the perfect com bustion of 7 pounds of carbon? Ans. 81.2 lb.

2. A fuel is 88 per cent. carbon and 12 per cent. hydrogen. How many cubic feet of air are required for the complete combustion of 1 pound of the fuel? Ans. 188.6 cu. ft.

3. (*a*) How many British thermal units would the combustion of the pound of fuel of example 2 give out? (*b*) How many pounds of water at 212° F. would 1 pound of this fuel evaporate?

Ans. $\begin{cases} (a)\ 20{,}288\ \text{B. T. U.} \\ (b)\ 21\ \text{lb.} \end{cases}$

4. The chemical symbol of the product of combustion of sulphur with oxygen is SO_2 (sulphurous oxide). What is the composition of this gas by weight?

Ans. $\begin{cases} \text{Sulphur, 50 per cent.} \\ \text{Oxygen, 50 per cent.} \end{cases}$

5. Assume that, with ordinary draft, double the theoretical quantity of air is used to burn a fuel. Under these circumstances, how many cubic feet of air will be required to burn 115 pounds of coal, the chemical composition being H, 5 parts; C, 90 parts; O, 3 parts; and ash, 2 parts; total, 100 parts? Ans. 36,719.5 cu. ft.

6. What is the heat of combustion of a pound of coal having the composition mentioned in example 5? Ans. 16,007.5 B. T. U.

STEAM

PROPERTIES OF STEAM

59. Formation.—**Steam** is water vapor; that is, it is water changed into a gaseous state by the application of heat. The process of changing water (or other liquid) into vapor by means of heat is called **evaporation** or **vaporization.**

When an open vessel containing water is placed in contact with fire, the air contained in the water is first driven off and escapes from the surface. The water in contact with the part of the vessel nearest the fire first receives the heat and expands. Its specific gravity is reduced; that is, it becomes lighter than the cooler water above it, and it rises to the surface, cooler water taking its place. In this manner the water keeps up a circulation until, at an atmospheric pressure of 14.7 pounds per square inch, it reaches a temperature of 212°. At this stage the molecules nearest the fire attain such a velocity of vibration that they rise through the water above them, overcome the pressure of the air, and escape in the form of a gas. When this occurs, the water boils.

60. Relation of Pressure and Temperature.—If the pressure on the surface of the water is increased, it will take more work to force the molecules to the surface; that is, more heat must be given to the water to make it boil, and therefore the boiling point will be raised. Water exposed to an atmospheric pressure of 14.7 pounds per square inch boils at a temperature of 212°. If the pressure is increased to, say, 32 pounds per square inch, the water will not boil until it reaches a temperature of 254°. On the other hand, if the pressure is lowered to 6 pounds per square inch, the water boils at 170°. Hence, the following law is derived:

Law.—*An increase of pressure on the surface of a liquid raises the boiling point; a decrease of pressure lowers the boiling point.*

61. Saturated Steam.—Steam in contact with water is called **saturated steam.** This is the condition of steam in

a boiler. Steam at a given pressure is also said to be saturated when its temperature is the same as the temperature at which water boils when subjected to the same pressure; this is true even though the steam is entirely separated from water. According to the law given in Art. **60**, the temperature of saturated steam depends only on the pressure. When the steam in a boiler shows a gauge pressure of 60 pounds, its temperature *must be* 307°. A thermometer placed in a boiler could be used to tell the pressure of the steam. It would be as accurate, though not as convenient, as a steam gauge.

The reader is cautioned against the idea that saturated steam necessarily implies "wet" steam. It may be perfectly free from water particles, but it is saturated if the pressure and temperature are mutually dependent. In the steam boiler, for example, the space above the water, if viewed through a glass-covered opening, appears to be perfectly transparent, as though filled with air, provided the boiler is not working. This shows that the steam that fills this space is perfectly "dry." When, however, the boiler is steaming rapidly, the violent ebullition may throw up a certain amount of water in the form of a spray, that mingles with the steam, giving it the misty appearance shown in the exhaust from an engine. Steam in this condition is *"wet" saturated steam.*

In physics the word saturation, whence the term *saturated steam* has been derived, has a meaning somewhat different from that commonly assigned to it. It means in physics the filling of a space with vapor to that point where condensation begins. Then, it may be said that saturated steam is steam subjected to a pressure at which condensation is about to begin; that is, the slightest abstraction of heat or the slightest increase in pressure will cause part of it to condense, and if the steam is separated from the water, the slightest addition of heat will cause it to become superheated.

62. Superheated Steam.—Steam separated from water may be heated like air or any other gas until its temperature is higher than the boiling point corresponding to its pressure.

To illustrate, put a little water in a cylinder open to the atmosphere, as shown in Fig. 16 at *a*. Suppose that the area of the cylinder is 100 square inches; then the pressure of the atmosphere on the piston is $14.69 \times 100 = 1,469$ pounds. The number 14.69 is a little more exact than 14.7 for the normal atmospheric pressure at sea level.

When a part of the water is changed to steam, as at *b*, Fig. 16, the steam is in a saturated state, and at this pressure its temperature cannot be higher than 212°. When, however, the water is all changed to steam, as at *c*, Fig. 16, any further

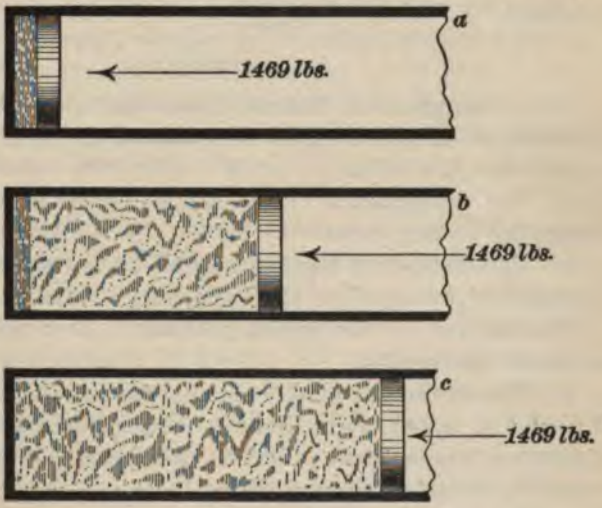


FIG. 16

addition of heat raises its temperature, while the pressure remains at 14.69 pounds per square inch. Steam in this latter condition is known as **superheated steam.**

The specific heat of superheated steam at constant pressure is .4805, or, say, .48 for ordinary purposes; that is, .48 British thermal unit will raise the temperature of 1 pound of superheated steam 1°. The temperature of saturated steam cannot be raised if the pressure remains constant. All the heat is expended in changing water to steam, and until all the water is vaporized the temperature remains constant.

If the steam in the cylinder has been subjected to a uniform pressure greater than that of the atmosphere, its temperature will be correspondingly higher; but as long as any water remains, any addition of heat will merely change more of the water to steam without increasing the temperature. As soon, however, as the last drop of water is gone, the effect of adding more heat will be to increase the temperature. Superheated steam may therefore be defined as steam separated from water and heated so as to give it a temperature higher than the boiling point corresponding to its pressure.

STEAM TABLE

63. Changes of Steam Properties.—Whenever the pressure of saturated steam is changed, the following properties change with it:

1. The temperature of the steam, or, what is the same thing, the boiling point.

2. The number of British thermal units required to raise 1 pound of water from 32° (freezing) to the boiling point corresponding to the given pressure. This is called the **heat of the liquid.**

3. The number of British thermal units required to change 1 pound of water at the boiling temperature into steam at the same temperature. This is called the **latent heat of vaporization**, or simply **latent heat.**

4. The number of British thermal units required to change 1 pound of water at 32° to steam of the required temperature and pressure. This is called the **total heat of vaporization**, or simply **total heat.**

It is plain that the total heat is the sum of the heat of the liquid and the latent heat. That is, total heat = heat of liquid + latent heat.

5. The **specific volume** of the steam at the given pressure; that is, the number of cubic feet occupied by 1 pound of steam at the given pressure.

6. The **density** of the steam; that is, the weight of 1 cubic foot of the steam at the given pressure.

All these properties vary with the pressure of the steam. It at sea level steam is at atmospheric pressure, the temperature is 212°; the heat of the liquid is 180.531 British thermal units; the latent heat, 966.069 British thermal units; the total heat, 1,146.6 British thermal units. A pound of steam at this pressure occupies 26.37 cubic feet and 1 cubic foot of the steam weighs about .037928 pound. When the pressure is 70 pounds per square inch above vacuum, the temperature is 302.774°; the heat of the liquid is 272.657 British thermal units; the latent heat is 901.629 British thermal units; the total heat, 1,174.286 British thermal units. A pound of the steam occupies 6.076 cubic feet, and 1 cubic foot of the steam weighs .164584 pound.

These properties have been determined by direct experiment for all ordinary steam pressures, and are given in the table Properties of Saturated Steam.

64. Explanation of Steam Table.—Column 1 gives the pressures from 1 to 300 pounds. These pressures are above vacuum. The steam gauges fitted on steam boilers register the pressure above the atmosphere. That is, if the steam is at atmospheric pressure, 14.7 pounds per square inch, the gauge registers 0. Consequently, the atmospheric pressure must be added to the reading of the gauge to obtain the pressure above vacuum. In using the table, care must be taken *not* to use the gauge pressures without first adding 14.7 pounds per square inch for places at sea level. As the pressure of the atmosphere varies with the altitude, the true atmospheric pressure can always be obtained by consulting the barometer. The barometric reading should be reduced to pounds pressure per square inch and added to the gauge pressure in order to obtain the correct absolute pressure for the time and place. However, in nearly all engineering calculations, it is customary to take the pressure of the atmosphere at 14.7 pounds per square inch. Pressures registered above vacuum are called **absolute pressures.**

Column 2 gives the temperature of the steam when at the pressure shown in column 1.

Column 3 gives the heat of the liquid. It will be noticed that the values in column 3 may be obtained, approximately, by subtracting 32° from the temperature in column 2. If the specific heat of water were exactly 1.00, it would, of course, take exactly $212 - 32 = 180$ British thermal units to raise 1 pound of water from 32° to 212°. But, experiment shows that the specific heat of water is slightly greater than 1.00 when the temperature of the water is above 62°, and it therefore takes 180.531 British thermal units to raise 1 pound of water from 32° to 212°.

Column 4 gives the latent heat of vaporization, which is seen to decrease slightly as the pressure increases.

Column 5 gives the total heat of vaporization. The values in column 5 may be obtained by adding together the corresponding values in columns 3 and 4.

Column 6 gives the weight of 1 cubic foot of steam, in pounds. As would be expected, as the pressure increases the steam becomes denser and weighs more per cubic foot.

Column 7 gives the number of cubic feet occupied by 1 pound of steam at the given pressure. It will be noticed that the corresponding values of columns 6 and 7 multiplied together always produce 1. That is, for 31.3 pounds gauge pressure, $.110884 \times 9.018 = 1.000$, nearly.

Column 8 gives the ratio of the volume of 1 pound of steam at the given pressure and the volume of 1 pound of water at 39.1°. The values in column 8 may be obtained by dividing 62.425, the weight of 1 cubic foot of water at 39.1°, by the numbers in column 6.

65. Directions for Using Steam Table.—Manifestly it would be impossible to compile steam tables that would include the values corresponding to all pressures. The table given covers the range of pressures likely to be met in practice. For values that are not given in the table, though within its range, a method of calculation known as **interpolation** may be used. In finding the values of t, q, L, etc. for an absolute pressure of, say, 76.35 pounds per square inch, use must be made of the two values of t, q, L, etc., and

also of the two values of p given in the table that are nearest to 76.35 pounds; that is, the nearest given value of p that is less than 76.35 pounds and that which is greater than 76.35 pounds. In the present case, these two values are 76 pounds and 78 pounds. In like manner, for any other given value of p that, though within the range of the table, is not given, use must be made of the two values of p between which it is included.

66. The method of using the table is illustrated by the following examples and their accompanying solutions.

What are the values of t, q, L, H, V, and W for steam whose gauge pressure is 61.65 pounds per square inch?

The pressures in the Steam Table are absolute pressures; hence, when the gauge pressure of steam is given, 14.7, or whatever may be the normal atmospheric pressure at that time, must be added to it in order to use it in connection with the table. Therefore,

$$p = 61.65 + 14.7 = 76.35 \text{ pounds per square inch.}$$

Turning to the table, it is seen that this pressure lies between the two given values 76 and 78.

(*a*) To find t (temperature):

$$\begin{array}{lll} \text{For } p = & 78 \text{ pounds, } t = & 310.123° \\ \text{For } p = & \underline{76} \text{ pounds, } t = & \underline{308.344°} \\ \text{Difference, } & 2 \text{ pounds, } & 1.779° \end{array}$$

For a difference in pressure of 2 pounds, there exists a difference in temperature of 1.779°. A difference in pressure of 1 pound will, therefore, give a difference in temperature of $\frac{1.779}{2} = .8895°$. The actual difference in pressure for this case is $76.35 - 76 = .35$ pound. Hence, the actual difference in temperature will be $.35 \times .8895 = .311325°$, say, .311°. This means that if the pressure of saturated steam is changed from 76 pounds per square inch to 76.35 pounds per square inch, its temperature is raised through .311°. Its temperature at 76 pounds pressure is 308.344°,

consequently, its temperature at 76.35 pounds pressure is 308.344 + .311 = 308.655°.

(*b*) To find q (sensible heat):

For p =	78 pounds,	q =	280.170 B. T. U.
For p =	76 pounds,	q =	278.350 B. T. U.
Difference,	2 pounds,		1.820 B. T. U.

For a difference in 1 pound pressure there will be a difference in q of $\frac{1.820}{2}$ = .91 B. T. U.; for a difference in .35 pound pressure there is a difference in q of .91 × .35 = .3185 B. T. U. Hence, the sensible heat q, corresponding to a pressure of 76.35 pounds per square inch, is 278.350 + .3185 = **278.6685** B. T. U.

(*c*) To find L (latent heat):

For p =	76 pounds,	L =	897.635 B. T. U.
For p =	78 pounds,	L =	896.359 B. T. U.
Difference,	2 pounds,		1.276 B. T. U.

For a difference of 1 pound pressure, the difference in latent heat is $\frac{1.276}{2}$ = .638 B. T. U. .638 × .35 = .2233 B. T. U. By comparing p and L in the table, it will be seen that as p increases L decreases. In the present case, therefore, there must be subtracted from the value of L corresponding to a pressure of 76 pounds the difference due to the actual difference in pressures. That is, for p = 76.35 pounds, L = 897.635 − .2233 = 897.4117 B. T. U.

(*d*) To find H (total heat):

For p =	78 pounds,	H =	1,176.529 B. T. U.
For p =	76 pounds,	H =	1,175.985 B. T. U.
Difference,	2 pounds,		.544 B. T. U.

As above, $\frac{.544}{2}$ = .272; .272 × .35 = .0952 B. T. U. Hence, for p = 76.35 pounds, H = 1,175.985 + .0952 = **1,176.0802** B. T. U. Ans.

(e) To find W (weight per cubic foot):

For p = 78 pounds (pressure),	W = .182229	pound (weight)
For p = 76 pounds (pressure),	W = .177825	pound (weight)
Difference, 2 pounds (pressure),	.004404	pound (weight)

Proceeding as before, $\frac{.004404}{2} = .002202$; $.002202 \times .35 = .0007707$. Hence, for $p = 76.35$ pounds, $W = .177825 + .0007707 = .1785957$ pound.

(f) To find V (volume of 1 pound):

For p = 76 pounds,	V = 5.624	cubic feet
For p = 78 pounds,	V = 5.488	cubic feet
Difference, 2 pounds,	.136	cubic foot

As before, $\frac{.136}{2} = .068$; $.068 \times .35 = .0238$ cubic foot.

Here V decreases as p increases. Hence, as in (c), the difference must be subtracted from the value of V corresponding to 76 pounds, getting for $p = 76.35$ pounds, $V = 5.624 - .0238 = 5.6002$ cubic feet.

EXAMPLE 1.—Calculate the heat required to change 5 pounds of water at 32° into steam at 92 pounds pressure above vacuum.

SOLUTION.—From column 5, the total heat of 1 lb. at 92 lb. pressure is 1,180.045 B. T. U.

$1,180.045 \times 5 = 5,900.225$ B. T. U. Ans.

EXAMPLE 2.—How many British thermal units are required to raise 8½ pounds of water from 32° to 250° F.?

SOLUTION.—Looking in column 3, the heat of the liquid of 1 lb. at 250.293° is 219.261 B. T. U. 219.261 − .293 = 218.968 B. T. U. = heat of liquid for 250°. Then, for 8½ lb. it is 218.968 × 8½ = 1,861.228 B. T. U. Ans.

EXAMPLE 3.—How many foot-pounds of work will it require to change 60 pounds of boiling water at 80 pounds pressure, absolute, into steam of the same pressure?

SOLUTION.—Looking under column 4, the latent heat of vaporization is 895.108; that is, it takes 895.108 B. T. U. to change 1 lb. of water at 80 lb. pressure into steam of the same pressure. Therefore, it takes 895.108 × 60 = 53,706.48 B. T. U. to perform the same operation on 60 lb. of water.

$53,706.48 \times 778 = 41,783,641.44$ ft.-lb. Ans.

EXAMPLE 4.—Find the volume occupied by 14 pounds of steam at 30 pounds gauge pressure at sea level.

SOLUTION.— 30 lb. gauge pressure = 30 + 14.7 = 44.7 lb. absolute pressure. The nearest pressure in the table is 44 lb. and the volume of a pound of steam at that pressure is 9.403 cu. ft. The volume of a pound at 46 lb. pressure is 9.018 cu. ft. 9.403 − 9.018 = .385 cu. ft., the difference in volume for a difference in pressure of 2 lb. $\frac{.385}{2}$ = .1925 cu. ft., the difference in volume for a difference in pressure of 1 lb. .1925 × .7 = .135 cu. ft., the difference in volume for a difference in pressure of .7 lb. Therefore, 9.403 − .135 = 9.268 cu. ft. is the volume of 1 lb. of steam at 44.7 lb. pressure. The .135 cu. ft. is subtracted from 9.403 cu. ft., since the volume is less for a pressure of 44.7 lb. than for 44 lb.

9.268 × 14 = 129.752 cu. ft. Ans.

EXAMPLE 5.—Find the weight of 40 cubic feet of steam at a temperature of 254° F.

SOLUTION.—The weight of 1 cu. ft. of steam at 254.002°, from the table, is .078839 lb. Neglecting the .002°, the weight of 40 cu. ft. is, therefore,

.078839 × 40 = 3.15356 lb. Ans.

EXAMPLE 6.—How many pounds of steam at 64 pounds pressure, absolute, are required to raise the temperature of 300 pounds of water from 40° to 130° F., the water and steam being mixed together?

SOLUTION.—The number of heat units required to raise 1 lb. from 40° to 130° is 130 − 40 = 90 B. T. U. (Actually a little more than 90 would be required, but the above is near enough for all practical purposes.) Then, to raise 300 lb. from 40° to 130° requires 90 × 300 = 27,000 B. T. U. This quantity of heat must necessarily come from the steam. Now, 1 lb. of steam at 64 lb. pressure gives up, in condensing, its latent heat of vaporization, or 905.9 B. T. U. But in addition to its latent heat, each pound of steam on condensing must give up an additional amount of heat in falling to 130°. Since the original temperature of the steam was 296.805° F. (see table), each pound gives up by its fall of temperature 296.805 − 130 = 166.805 B. T. U. Therefore, each pound of the steam gives up a total of 905.9 + 166.805 = 1,072.705 B. T. U. It will, therefore, take $\frac{27,000}{1,072.705}$ = 25.17 lb. of steam to accomplish the desired result. Ans.

EXAMPLE 7.—How much steam at 2 pounds gauge pressure will be condensed in a pipe coil to heat 8,300 pounds of water from 60° F. to 180° F., the condensed steam being discharged at the temperature corresponding to 2 pounds gauge pressure?

SOLUTION.— 2 lb. gauge pressure = 2 + 14.7 = 16.7 lb. absolute pressure. Since the condensed steam is discharged under the same pressure it had when in the gaseous form, it parts only with its latent heat. By interpolation, the latent heat of 1 lb. of steam at 16.7 lb. pressure is found to be 961.475 B. T. U. To heat 8,300 lb. of water from 60° F. to 180° F. requires 8,300 × (180 − 60) = 996,000 B. T. U. Then, there will be $\frac{996{,}000}{961.475}$ = 1,036 lb. of steam required. Ans.

QUALITY OF STEAM

67. In order to measure the amount of heat that is contained in any certain amount of steam and that will be given off in cooling and condensing, it is necessary that the pressure and dryness of the steam be carefully ascertained.

The steam that is used for heating purposes and for power is seldom dry, but is mixed with a greater or less percentage of water, which is suspended in the steam in the form of vapor. The presence of water in the steam greatly impairs its value as a heating agent. Thus, 10 pounds of wet steam containing 10 per cent. of moisture consists of 9 pounds of dry steam and 1 pound of hot water. At an absolute pressure of 26 pounds it is found from the table, Properties of Saturated Steam, that above 32° F., 9 pounds of dry steam contains 10,402.4 British thermal units, and 1 pound of water contains 211.1 British thermal units. Then, 10 pounds of the wet steam contains 10,402.4 + 211.1 = 10,613.5 British thermal units. Since 10 pounds of dry steam contains 11,558.2 British thermal units, there is a loss of 11,558.2 − 10,613.5 = 944.7 British thermal units in using 10 pounds of steam at the absolute pressure of 26 pounds, containing 10 per cent. of moisture, and cooling it to 32° F.

68. The percentage of dry steam contained in a given weight of wet steam is called the **quality of the steam**, and is determined by means of an instrument called a **calorimeter.** The form designed by Prof. R. C. Carpenter, of Cornell University, and known as the *separating calorimeter*, is shown in Fig. 17. The steam to be tested is passed through the pipe *a* and head *b* into the mechanical

TABLE VIII

PROPERTIES OF SATURATED STEAM

Pressure Above Vacuum Pounds per Square Inch	Temperature Degrees Fahrenheit	Quantities of Heat in British Thermal Units: Required to Raise Temperature of Water from 32° to t°	Quantities of Heat in British Thermal Units: Total Latent Heat at Pressure P	Quantities of Heat in British Thermal Units: Total Heat Above 32°	Weight of Cubic Foot of Steam Pounds	Volume of Pound of Steam Cubic Feet	Ratio of Volume of Steam to Volume of Equal Weight of Distilled Water at Temperature of Maximum Density
1	2	3	4	5	6	7	8
p	t	q	L	H	W	V	R
1	102.018	70.040	1043.015	1113.055	.003027	330.4	20623
2	126.302	94.368	1026.094	1120.462	.005818	171.9	10730
3	141.654	109.764	1015.380	1125.144	.008522	117.3	7325
4	153.122	121.271	1007.370	1128.641	.011172	89.51	5588
5	162.370	130.563	1000.899	1131.462	.013781	72.56	4530
6	170.173	138.401	995.441	1133.842	.016357	61.14	3816
7	176.945	145.213	990.695	1135.908	.018908	52.89	3302
8	182.952	151.255	986.485	1137.740	.021436	46.65	2912
9	188.357	156.699	982.690	1139.389	.023944	41.77	2607
10	193.284	161.660	979.232	1140.892	.026437	37.83	2361
11	197.814	166.225	976.050	1142.275	.028911	34.59	2159
12	202.012	170.457	973.098	1143.555	.031376	31.87	1990
13	205.929	174.402	970.346	1144.748	.033828	29.56	1845
14	209.604	178.112	967.757	1145.869	.036265	27.58	1721
14.69	212.000	180.531	966.069	1146.600	.037928	26.37	1646
15	213.067	181.608	965.318	1146.926	.038688	25.85	1614
16	216.347	184.919	963.007	1147.926	.041109	24.33	1519
17	219.452	188.056	960.818	1148.874	.043519	22.98	1434
18	222.424	191.058	958.721	1149.779	.045920	21.78	1359
19	225.255	193.918	956.725	1150.643	.048312	20.70	1292
20	227.964	196.655	954.814	1151.469	.050696	19.73	1231.0
22	233.069	201.817	951.209	1153.026	.055446	18.04	1126.0
24	237.803	206.610	947.861	1154.471	.060171	16.62	1038.0
26	242.225	211.089	944.730	1155.819	.064870	15.42	962.3
28	246.376	215.293	941.791	1157.084	.069545	14.38	897.6
30	250.293	219.261	939.019	1158.280	.074201	13.48	841.3
32	254.002	223.021	936.389	1159.410	.078839	12.68	791.8
34	257.523	226.594	933.891	1160.485	.083461	11.98	748.0

TABLE VIII—(*Continued*)

Pressure Above Vacuum Pounds per Square Inch	Temperature Degrees Fahrenheit	Quantities of Heat in British Thermal Units: Required to Raise Temperature of Water from 32° to t°	Total Latent Heat at Pressure P	Total Heat Above 32°	Weight of Cubic Foot of Steam Pounds	Volume of Pound of Steam Cubic Feet	Ratio of Volume of Steam to Volume of Equal Weight of Distilled Water at Temperature of Maximum Density
1	2	3	4	5	6	7	8
p	t	q	L	H	W	V	R
36	260.883	230.001	931.508	1161.509	.088067	11.36	708.8
38	264.093	233.261	929.227	1162.488	.092657	10.79	673.7
40	267.168	236.386	927.040	1163.426	.097231	10.28	642.0
42	270.122	239.398	924.940	1164.329	.101794	9.826	613.3
44	272.965	242.275	922.919	1165.194	.106345	9.403	587.0
46	275.704	245.061	920.968	1166.029	.110884	9.018	563.0
48	278.348	247.752	919.084	1166.836	.115411	8.665	540.9
50	280.904	250.355	917.260	1167.615	.119927	8.338	520.5
52	283.381	252.875	915.494	1168.369	.124433	8.037	501.7
54	285.781	255.321	913.781	1169.102	.128928	7.756	484.2
56	288.111	257.695	912.118	1169.813	.133414	7.496	467.9
58	290.374	260.002	910.501	1170.503	.137892	7.252	452.7
60	292.575	262.248	908.928	1171.176	.142362	7.024	438.5
62	294.717	264.433	907.396	1171.829	.146824	6.811	425.2
64	296.805	266.566	905.900	1172.466	.151277	6.610	412.6
66	298.842	268.644	904.443	1173.087	.155721	6.422	400.8
68	300.831	270.674	903.020	1173.694	.160157	6.244	389.8
70	302.774	272.657	901.629	1174.286	.164584	6.076	379.3
72	304.669	274.597	900.269	1174.866	.169003	5.917	369.4
74	306.526	276.493	898.938	1175.431	.173417	5.767	360.0
76	308.344	278.350	897.635	1175.985	.177825	5.624	351.1
78	310.123	280.170	896.359	1176.529	.182229	5.488	342.6
80	311.866	281.952	895.108	1177.060	.186627	5.358	334.5
82	313.576	283.701	893.879	1177.580	.191017	5.235	326.8
84	315.250	285.414	892.677	1178.091	.195401	5.118	319.5
86	316.893	287.096	891.496	1178.592	.199781	5.006	312.5
88	318.510	288.750	890.335	1179.085	.204155	4.898	305.8
90	320.094	290.373	889.196	1179.569	.208525	4.796	299.4
92	321.653	291.970	888.075	1180.045	.212892	4.697	293.2

TABLE VIII—(*Continued*)

Pressure Above Vacuum Pounds per Square Inch	Temperature Degrees Fahrenheit	Quantities of Heat in British Thermal Units			Weight of Cubic Foot of Steam Pounds	Volume of Pound of Steam Cubic Feet	Ratio of Volume of Steam to Volume of Equal Weight of Distilled Water at Temperature of Maximum Density
		Required to Raise Temperature of Water from 32° to t°	Total Latent Heat at Pressure P	Total Heat Above 32°			
1	2	3	4	5	6	7	8
p	t	q	L	H	W	V	R
94	323.183	293.539	886.972	1180.511	.217253	4.603	287.3
96	324.688	295.083	885.887	1180.970	.221604	4.513	281.7
98	326.169	296.601	884.821	1181.422	.225950	4.426	276.3
100	327.625	298.093	883.773	1181.866	.230293	4.342	271.1
105	331.169	301.731	881.214	1182.945	.241139	4.147	258.9
110	334.582	305.242	878.744	1183.986	.251947	3.969	247.8
115	337.874	308.621	876.371	1184.992	.262732	3.806	237.6
120	341.058	311.885	874.076	1185.961	.273500	3.656	228.3
125	344.136	315.051	871.848	1186.899	.284243	3.518	219.6
130	347.121	318.121	869.688	1187.809	.294961	3.390	211.6
135	350.015	321.105	867.590	1188.695	.305659	3.272	204.2
140	352.827	324.003	865.552	1189.555	.316338	3.161	197.3
145	355.562	326.823	863.567	1190.390	.326998	3.058	190.9
150	358.223	329.566	861.634	1191.200	.337643	2.962	184.9
160	363.346	334.850	857.912	1192.762	.358886	2.786	173.9
170	368.226	339.892	854.359	1194.251	.380071	2.631	164.3
180	372.886	344.708	850.963	1195.671	.401201	2.493	155.6
190	377.352	349.329	847.703	1197.032	.422280	2.368	147.8
200	381.636	353.766	844.573	1198.339	.443310	2.256	140.8
210	385.759	358.041	841.556	1199.597	.464295	2.154	134.5
220	389.736	362.168	838.642	1200.810	.485237	2.061	128.7
230	393.575	366.152	835.828	1201.980	.506139	1.976	123.3
240	397.285	370.008	833.103	1203.111	.527003	1.898	118.5
250	400.883	373.750	830.459	1204.209	.547831	1.825	114.0
260	404.370	377.377	827.896	1205.273	.568626	1.759	109.8
270	407.755	380.905	825.401	1206.306	.589390	1.697	105.9
280	411.048	384.337	822.973	1207.310	.610124	1.639	102.3
290	414.250	387.677	820.609	1208.286	.630829	1.585	99.0
300	417.371	390.933	818.305	1209.238	.651506	1.535	95.8

separator *c*. The steam escapes through a series of fine holes, and passes over the edge of the cup *d* into the outer space *e*. It passes out thence through the shank *f* and hose *g* to a condenser *h*, where it is condensed. The sudden change of direction of the flow of the steam in passing through the fine orifices in *c* causes the water that is suspended in the steam to be thrown into the cup *d*. The quantity of water thus caught in the cup is shown by the gauge glass *i*. The scale *j* is so graduated that each division indicates $\frac{1}{100}$ pound. The separator frees the steam from entrained water in a very perfect manner, so that only practically dry steam passes to the condenser.

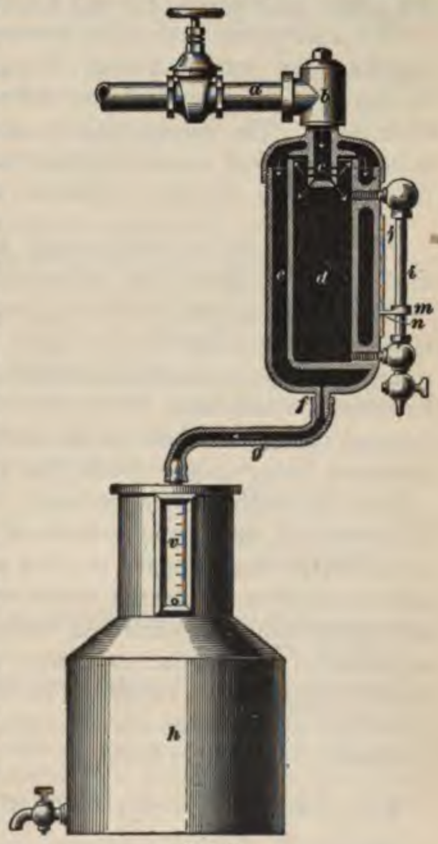


Fig. 17

The rate of flow of steam is limited by the size of the orifice in *f*, which is usually $\frac{1}{16}$ inch. Condensation with steam at 60 pounds gauge pressure will occur at the rate of about 1 pound in 3 minutes. The condenser should contain from 75 to 80 pounds of water, which should be as cold as can conveniently be obtained, and should fill the condenser to or a little above the zero of the scale *v*. Each division of the scale indicates $\frac{1}{10}$ pound. As the steam condenses, the water level will rise, and the difference between the successive readings of the

scale indicates the weight of dry steam actually condensed. Readings should be taken simultaneously on the scales v and j, at the beginning and end of each test. The steam pressure should be accurately measured at the same time. The weight of steam actually tested is the sum of the weights of the steam condensed in h and the water that is caught in d.

The instrument must be warmed up slowly, to avoid breaking the gauge glass. The full pressure of steam should then be admitted, and maintained until all tests are completed. The valve and pipe connections should be protected with good non-conducting material, but the body of the instrument and the condenser should be left uncovered.

69. If steam is superheated, it obviously contains no moisture, and hence the separating calorimeter does not indicate superheating. The degree and amount of superheat is most readily found by the aid of a high-temperature thermometer and an accurate steam gauge. The difference between the indication of the thermometer and the temperature of saturated steam at the indicated pressure, the temperature being taken from the steam table, will be the number of degrees of superheat. If this number be multiplied by .48, the specific heat of superheated steam, the product will represent the number of British thermal units a pound of the superheated steam will give up in cooling to the temperature of saturated steam at the same pressure; conversely, the product will also represent the number of British thermal units expended in raising the saturated steam from the temperature corresponding to its pressure to that indicated by the thermometer.

70. The quality of wet saturated steam is found as follows:

Rule.—*To find the quality of steam from the indications of a separating calorimeter, divide the weight of condensed water in the condenser by the sum of the weights of the condensed water in the condenser and the entrained water collected in the separator.*

Or,
$$Q = \frac{W}{W + w}$$

where Q = quality of steam;
W = weight of condensed water;
w = weight of water in separator.

EXAMPLE.—The initial reading of the scale on the separator was .04 pound and the final reading .28 pound. The scale on the condenser indicated .6 pound at the beginning and 16.8 pounds at the ending of the test. What is the quality of the steam?

SOLUTION.—Water in separator = .28 − .04 = .24 lb. Water in condenser = 16.8 − .6 = 16.2 lb. Applying the formula,

$$Q = \frac{16.2}{16.2 + .24} = .9854 = 98.54 \text{ per cent. Ans.}$$

EXAMPLES FOR PRACTICE

1. How many foot-pounds of work are required to change 42 pounds of water at the temperature corresponding to a pressure of 88 pounds, absolute, into steam at a temperature corresponding to a pressure of 105 pounds, absolute? Ans. 29,208,194.15 lb.

2. How many British thermal units are required to convert 25 pounds of water at 32° into 109.6 cubic feet of steam? Ans. 29,541.1 B. T. U.

3. Find the number of British thermal units required to change 11 pounds of water at 32° into steam at 100 pounds absolute pressure. Ans. 13,000.526 B. T. U.

4. Find the weight of 712 cubic feet of steam at a pressure of 33 pounds, gauge. Ans. 81.689 lb.

5. How many pounds of steam at 47.3 pounds pressure, gauge, are required to raise 120 pounds of water from 55° to 160° at atmospheric pressure? Ans. 12.091 lb.

6. Find the volume of 19 pounds of steam at a pressure of 62 pounds, gauge. Ans. 105.952 cu. ft.

7. Find the quality of the steam when the separator scale indicated .01 and .31 pound, and the condenser scale .2 and 19.5 pounds at the original and final readings. Ans. 98.47 per cent.

PRINCIPLES OF AIR HEATING

TRANSMISSION OF HEAT TO AIR

FUNDAMENTAL PRINCIPLES

71. It is commonly supposed that air can be readily warmed by means of radiant heat, because of the apparent effects of the rays of the sun in warming the atmosphere. This belief, however, is a fallacy. It is a well-established fact that radiant heat produces no perceptible effect on air that is pure and dry. But it is intercepted and readily absorbed by dust and the vapor of water, and since these substances are always present in the atmosphere, they operate to absorb heat from the sun's rays, and to impart heat, by conduction, to the air with which they are intermingled. The atmosphere is also warmed by contact with the earth. At a height of 3 miles or more, the air is nearly free from moisture and dust, and is intensely cold at all times. The highest part of the atmosphere that is warm enough to live in comfortably is that within a mile or so of the earth's surface.

Air can be heated only by conduction; that is, by direct contact with hot surfaces or substances. The prime requisite of an apparatus for heating air is an abundance of hot surfaces over which the air may travel. Heating surfaces, when in operation, are covered with a thin layer, or film, of hot air, which clings to the metal with considerable pertinacity. Since the air in this film is practically motionless, it is usually called **dead air**. All heat that is imparted to the cooler air outside must be transmitted through this film by conduction. If the air is not in perceptible motion, the film will be quite thick and the transmission of heat will be slow; but, if the air is moved in a current over the hot surface, the film of dead air will be reduced in thickness and will be partly

swept away, and the rate of heat transmission will be increased accordingly. It is evident, therefore, that where air is to be heated, circulation of it is very necessary.

72. There are two methods of securing air circulation: the *natural-draft* system, which operates wholly by convection, and the *forced-draft* system, in which the air is propelled by fans or blowers. If the air is moved by mechanical means, any desired velocity may be given to it. By using a high velocity, the heating surfaces may be continually

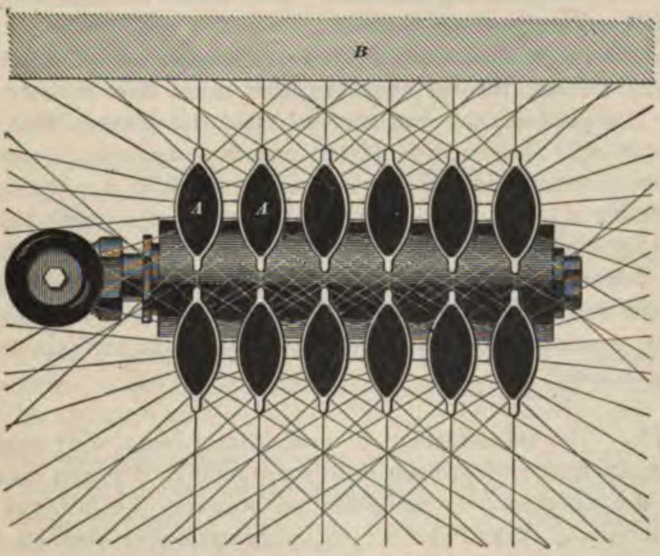


FIG. 18

swept clean of adherent hot air, thus enabling the transmission of heat to be made with maximum rapidity. The currents that are induced by convection move at very moderate velocities; consequently, the heating surfaces cannot give the same degree of efficiency as with the forced-draft system.

73. Fig. 18 shows, in horizontal section, the loops A, A of a radiator that is fitted up at the usual distance from the wall B. Radiant heat is transmitted from the surfaces as

indicated by the radiating lines. An examination of the lines will show how most of the rays of heat impinge on the radiator loops and the back wall. The air between the loops becomes heated by convection, by being brought into direct contact with them; it thus becomes lighter, and is buoyed upwards, as it were, by the colder, heavier air in the room. When this hot air leaves the radiator, it continues to flow upwards, and while flowing, it mixes, to a certain extent, with the colder air surrounding it, and thereby becomes perceptibly decreased in temperature before it reaches the ceiling.

Since the heated air thus leaves the radiator and flows up to the ceiling, the air near the floor must flow in between the surfaces of the radiator to take its place. This, of course, will also become heated and flow upwards; hence, a constant circulation of air is going on while a radiator is warming a room, the upward, or flow, currents being immediately over, or near, the heating surfaces, and the return, or downward, currents elsewhere about the room. The return currents that fall with the greatest velocity are those near exposed windows and near the walls farthest from the radiator.

74. The transmission of heat from a radiator or similar heating device to the air that surrounds it depends mainly on the difference in temperature between the hot gas or fluid within it and the air to be heated, and also on the velocity given to the film of air that is in close contact with the heating surfaces. It is affected, in a small degree, by the form of the heating surfaces and also by their condition, whether smooth or rough. Neither the kind of metal employed nor its thickness (within the range usually employed for such purposes) seems to make much difference. The number of British thermal units transmitted per hour through 1 square foot of emitting surface, for each degree of difference in temperature between the fluids on the opposite sides of the heating surface, is called the **coefficient of emission** of that heating surface.

The conditions that impede the emission of heat by radiation have a much smaller effect on the transmission of heat by conduction. The proportion of heat emitted by radiation in radiators employed for direct heating is seldom more than 30 or 40 per cent. of the total emission; and it is practically nothing in indirect heating. As air is not heated appreciably by radiant heat, the use of the word *radiator* to indicate a steam heater, etc. is clearly wrong; but the usage is so firmly established that the error cannot very well be corrected.

In experimenting with the condition of heating surfaces it is found that, with surfaces of various kinds, the emission of heat is about as follows, the total emission from a new cast-iron plate having its natural surface (as cast) being taken as 1:

Cast iron, new	1.00
Cast iron, rusty	1.02
Wrought iron, ordinary or "black"	.93
Wrought iron, bright, but not polished	.72
Surface covered with lampblack, dull	1.06
Surface covered with white-lead powder, dull	1.06

It is found, also, that the emission is affected by painting or bronzing about as follows, the amount given off without paint being taken as 1:

Two coats of asphaltum paint	1.06
Two coats of white-lead paint, dull	1.09
Rough bronzing	1.06
One coat of glossy white paint	.90

This last item shows the effect of a glossy, or polished, surface in reducing the emission of heat.

75. In heating fluids of various kinds, it has been found, by experiment, that the amount of heat transmitted within a given time depends less on the kind of metal used in the radiator than on the nature of the fluids that are brought into contact with it.

Steam or hot water will impart heat to one side of a metal plate much faster than air will absorb it from the opposite side; consequently, there may be a considerable difference in

extent between the interior and exterior surfaces of a radiator tube that is employed for heating air, without any perceptible loss of efficiency. But, if the radiator is used to heat water, the inner and outer surfaces should be as nearly equal as possible, because water will absorb heat from the metal on one side as rapidly as the steam will impart it on the opposite side. The metal, then, should be made as thin as is consistent with strength and durability.

If hot gas is used to heat air, as in hot-air furnaces, the heat-absorbing and emitting surfaces should be of equal extent.

AIR-HEATING SURFACES

76. Form.—Heating surfaces that have no projections of any kind are classified as **plain surfaces**, while those having ribs, knobs, pins, or other projecting parts, are called **extended surfaces**.

The object sought in the construction of extended surfaces is to make the area of the emitting surface greater than that of the absorbing surface. By this means heat may be transferred, from a fluid that gives it off readily to one that takes it up slowly, with but little decrease in temperature of the heat-transmitting surfaces. A plate having extended surfaces will emit more heat per hour than the same plate without the extensions, but less than a plain plate having the same actual area of exposed surface. Thus, in Fig. 19 the internal surfaces marked c and d are of equal area, but the heat that passes through c is emitted from the whole exposed surface of the rib, or lug, while that which passes through d is emitted from a smaller surface. The emission through c will, therefore, be larger than that through d. This advantage is partly neutralized, however, by the lodgment of hot air in the spaces between the projections. The radiator becomes enveloped in a layer of hot air, which does not move away by convection. This greatly impedes

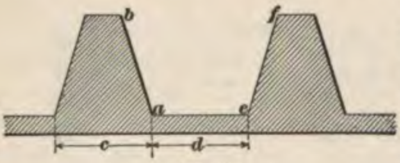


FIG. 19

the transmission of heat to the current of air that passes over the outer ends of the projections. The air will be warmer at the surface *a e* than at the points *b*, *f*.

Extended surfaces have no advantage over plain surfaces unless the velocity of the air passing over them is sufficient to sweep them clean of hot air as rapidly as it is formed. When air is moved wholly by convection, as is the case when a radiator stands in still air, the plain surfaces clear themselves of hot air better than the extended surfaces do, and they are therefore more effective.

In making comparisons between plain and extended surfaces, the area of the latter should be computed as though the projections were absent. It is a tedious and difficult task to compute the actual exposed area of extended surfaces, and such estimates are always liable to considerable inaccuracy. It is the custom of manufacturers, however, to rate extended surfaces by their actual exposed area. This practice is very misleading (especially to persons who are not aware of the lower efficiency of such surfaces) when the radiators are used in still air or in currents of low velocity.

77. The efficiency of a heater or radiator will increase as the velocity of air passing over it is increased, but not in the same proportion. With increased velocity, the duration of contact of air with the hot surface is shortened, and the rise of temperature will be less, but the quantity of air heated will be increased so much that the total heat given off from the radiator, per square foot of surface per hour, will be increased.

The coefficient of heat transmission increases approximately as the square root of the velocity of the air. Thus, if each square foot of surface emits 4 British thermal units per hour for each degree of difference in temperature of the steam and the cold air when the air moves 250 feet per minute, the rate of emission when the velocity of the air is raised to 500 feet per minute will be $\frac{\sqrt{500} \times 4}{\sqrt{250}} = 5.66$ British thermal units.

78. Arrangement.—The efficiency of a radiator will depend to a considerable extent on the direction in which the air is moved over the heating surfaces. Fig. 20 shows a vertical tube standing in still air. The tube is heated by steam, and its surface has a temperature that is practically uniform throughout. The air, which is warmed at the lower end of the tube, flows upwards and envelopes the upper part in a current of hot air. The emission of heat will be slower from the upper part of the tube than from the lower part, because the difference in temperature between the air and metal is less. An assumed temperature at the various points is marked on the sketch.

A similar loss of efficiency occurs in a common coil of horizontal pipes laid vertically over one another, as shown in Fig. 21. The upper pipes are enveloped in the warm air that has been heated by the lower pipes.

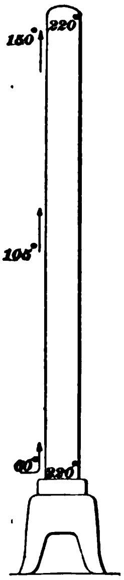


FIG. 20

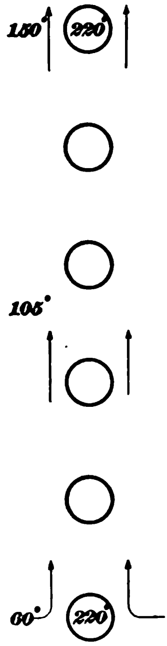


FIG. 21

The maximum efficiency can be attained by placing the coil or radiator in a horizontal position, as indicated in Fig. 22. Each tube will then operate on air of equally low temperature, and consequently the


FIG. 22

rate of emission will be greater than in the cases shown in Figs. 20 and 21.

If radiator tubes are grouped together in large numbers, as in Fig. 23, the efficiency of the tubes in the interior of

the group will be much less than that of the outside tubes, because the access of cold air to them is practically cut off, and they can act only on air that has been already warmed by the outer tubes. Their efficiency is still further reduced by the fact that nearly all of the heat that they emit by radiation is intercepted and cut off by the outer tubes.

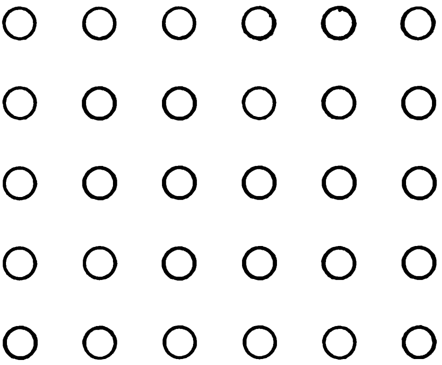


FIG. 23

Therefore, the most effective form of radiator or coil for direct heating is one having only a single row of tubes. If the inner tubes of a group can in some way be plentifully supplied with cold air, they will be as useful as the outer tubes. When forced circulation is employed, there is little difficulty in driving the cold air over the whole of the tubes; but with natural draft only, it is necessary to modify the shape and arrangement of the tubes to secure a satisfactory result.

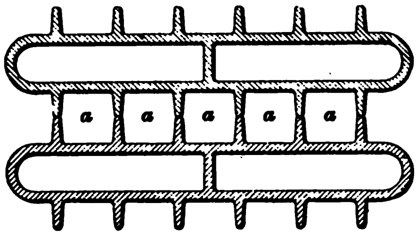


FIG. 24

79. Figs. 24 and 25 show varieties of radiator tubes that are so shaped that, when they are assembled in a group, they enclose vertical air flues, as shown at *a*. The bases of the tubes are set high enough above the floor to

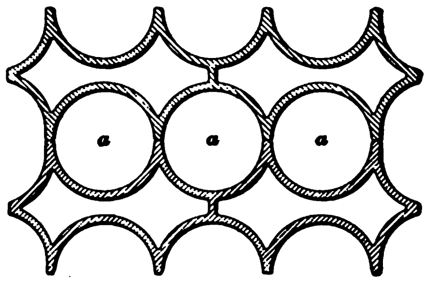


FIG. 25

permit an abundant flow of air into the flues at the bottom. Radiators constructed in this manner are called **flue radiators.** The advantages of this construction are that the interior parts of the radiator are fairly well supplied with air, and that the flues impart a higher velocity to the air than it would otherwise obtain. The emissive capacity of the two forms shown in Figs. 24 and 25 will vary greatly with the difference in the relative amount of plain and extended heated surfaces that they present, and also with the proportion of heating surface to the area of the flues.

HEATING OF BUILDINGS

METHODS

80. The methods of house heating now in vogue may be divided into two classes, called **direct** and **indirect.** The distinction between them consists solely in the mode of supplying the heat. In the direct method, the heat is emitted from stoves or radiators contained within the room to be warmed; in the indirect method, the heat is supplied by a current of hot air that is brought in from some outside source.

Several modifications and combinations of these methods are also used. The so-called **direct-indirect** method is one in which the room is warmed not only by the direct action of a radiator or heater, but also by a current of warmed fresh air that enters the room from the outer atmosphere. This fresh air is compelled to pass through the heater and become warmed before it mingles with the air in the room. The direct-indirect system is a combination of a system of direct heating with one of direct ventilation, the ventilation usually being limited to the room containing the heater. If there is no vent by which air may flow out of the room at the same time that the fresh air flows in, the current cannot be maintained, and the heater then operates like any direct heater.

Indirect heating systems are usually combined with a system of ventilation, but are sometimes operated without it.

Indirect heating is sometimes practiced by means of a heater, or stack, that takes cold air from a room and, after warming it, returns it to the same room through the ordinary hot-air flues and registers. This method is highly objectionable from a sanitary point of view, but is sometimes used for warming hallways or large rooms that contain only a very few people. The air within a room may be heated and kept warm, without introducing any fresh air, by either the direct or indirect method. Thus, it will be seen that ventilation is not inseparably connected with either system of heating.

81. The **direct heating system** is usually operated without any provision for ventilation, and it is not desirable, therefore, for warming dwellings or rooms that are occupied by people.

Direct heating apparatus emits heat both by radiation and by conduction. But, the method of warming apartments by means of radiated heat is a very poor and ineffective one, since radiant heat will not warm air directly. Air can be heated only by conduction and contact with warm surfaces; consequently, the heat that is radiated from the heater can only be utilized by an indirect process. It must be intercepted and absorbed by some intermediate body, which will thus become warm, and will in turn impart the heat by conduction to the surrounding atmosphere. This function is performed, in practice, by the walls of the room, the furniture, draperies, etc. The effect of the radiant heat on them is to spoil the varnish and the glued joints, and it also shrinks and cracks the woodwork, fades the hangings and carpets, and is particularly destructive to the bindings of books.

82. The old-fashioned, low-down **grates** are probably the least efficient form of heaters now in use. They have very little heating surface and operate mainly by radiating heat from the incandescent fuel. The heat contained in the products of combustion is usually carried off into the chimney and wasted. The same objections apply to *gas grates*, *gas logs*, and many forms of *gas stoves*. The reflecting gas stove has the additional defect of emitting strong light from

a point near the floor. Light proceeding from such a low level is very irritating to the eyes.

83. The ordinary plain, cylindrical **coal stove** is a heating device of low efficiency. The hot products of combustion are discharged into the chimney before they have time to give off any considerable part of their heat into the room. Thus the greater part of the heat evolved from the fuel goes to waste up the chimney. These stoves are very deficient in amount of heating surface. The stovepipe operates as a radiator, to some extent, by transmitting heat from the hot gases passing through it to the air around it. **Base heating stoves** are more efficient, because they are provided with flues that compel the hot gases to circulate under the lower part of the stove before passing off to the chimney. The amount of heating surface is thus increased, and the gases are given more time in which to impart their heat to the air of the room.

84. A **double heater** consists of a stove that is partly enclosed in a jacket. Cool air enters the lower end of the jacket, and becoming warmed by contact with the hot surface of the stove, ascends to the top and is discharged into the upper part of the room. The jacket increases the efficiency of the heater by increasing the velocity of the hot-air currents. The double heater may be easily adapted to the direct-indirect system of heating by supplying the jacket with fresh air through a duct leading from the outer atmosphere.

Double heaters might be called *furnaces*, but in practice the term is restricted to jacketed heaters of large size constructed with a large amount of heating surface, so that great quantities of air may be heated.

85. **Oil stoves** and **gas stoves** form a class of small portable stoves that burn oil or gas and are designed to heat single rooms. These are made singly, and also in groups; the former are called *stoves*, and the latter *radiators*. They are not usually connected to a chimney, and they mingle the products of combustion directly with the air of the room. The entire heat contained in the hot gases is

expended in warming the air, and in that respect they are remarkably effective heaters. But, for warming air that is to be breathed, nothing worse could be devised, since they vitiate the air very rapidly.

86. All cast-iron stoves have one defect, which is in some cases a serious one. When cast iron is heated to a visible dull-red heat, it is no longer gas-tight, and carbon monoxide will leak through it with considerable freedom. The gas seems to soak into one side of the cast-iron plate and to exude from the other, just as water will soak through a piece of blotting paper. Wrought-iron and steel plates do not pass gases to any noticeable extent, presumably because the metal has been changed in character during the process of manufacture. In any air-heating apparatus where the air passes over red-hot, cast-iron surfaces, it is very liable to be contaminated more or less by this poisonous gas.

GENERAL REQUIREMENTS

87. In order to satisfactorily heat and ventilate a room it is necessary to have:

1. A uniform distribution of heat throughout all parts of the room, as far as possible.
2. A thorough diffusion of fresh air throughout the level or zone in which persons breathe.
3. A prompt and complete removal of all foul air from the room.
4. A means of preventing all waste of heat, caused by the premature escape of the heated air.
5. A means of avoiding perceptible currents or drafts of either warm or cold air.

88. If the air in a room is cool near the floor and hot near the ceiling, the inmates of the apartment are likely to suffer from cold feet and congested heads. The congestion will produce headache, stupidity, and nervous irritability; and if long continued will lead to indigestion, weak sight, and general debility. It is especially injurious to school children. Study naturally produces some congestion in the head, and the evil

is greatly aggravated if they are also compelled to endure unequal heating. The first effect is to dull the perceptions and render study more difficult than it would otherwise be, thus defeating the purpose for which schools are maintained.

When persons are exposed to radiant heat on one side only, as when sitting in front of a grate or stove, they are liable to be warmed very unequally. The results are languor, drowsiness, and general depression. The effects of radiant heat on the back of a person are worse than on the front. It is not the exposure to *high* temperature merely that injures; it is the inequality of heat on the opposite parts of the body.

TEMPERATURE REGULATION

89. The method that may be used for controlling the temperature of the air within a building depends on the system of heating that is employed, and also on the heating agent, whether steam, hot water, or hot air. The emission of heat from a steam radiator may be graduated in several ways: (1) By dividing the radiator into several independent sections and admitting steam to more or less of them, as desired. (2) By admitting steam at full pressure and shutting it off again at moderate intervals, in regular alternation; the average temperature of the radiator thus obtained depends on the relative length and frequency of the intervals. (3) By varying the pressure of the steam. The first method is a good one and is used to some extent, but its general use is prevented by the lack of suitable apparatus. The expense of adapting the varieties of radiators now on the market and making the necessary connections with the valves of the ordinary kind is almost prohibitory.

The second method is usually carried out by means of automatic valves, which are similar in general principle to pressure-reducing valves.

The third method is commonly applied by varying the intensity of the fire under the boiler, or by the use of an automatic pressure-reducing valve, the adjustment being varied to give the desired steam pressure.

90. The emission of heat from a hot-water radiator may be graduated by adjusting the inlet valve, thus controlling the amount of hot water that flows through it.

91. When the indirect heating system is employed, the temperature of the air that is delivered by the apparatus may be controlled, not only by modifying the emission of heat from the radiators, but by mixing the hot air with a sufficient quantity of cold air to obtain the temperature desired. The former method is so slow in operation that it is not generally satisfactory; but the latter method produces the desired result very promptly and is also easy to manage.

92. When hot-air furnaces are used for heating, the methods of controlling the temperature by mixing or by operating the registers are the only ones which will give satisfaction. Regulation by varying the fire, even although it is most commonly done, is slow and uncertain, and inferior to the other methods named.

CHIMNEY DRAFT

THEORY

93. The upward motion of a column of air within a flue, or gases of combustion within a chimney, is called **draft.** Natural draft is produced by the difference between the weight of the column of gas within the chimney or flue and the weight of the same bulk of cold air. It is well known that any gas, when heated, is lighter, bulk for bulk, than when cool. Now, when the hot gases pass, say, into the chimney, they have a temperature of 400° or 500°, while the air outside the chimney has a temperature of from 40° to 90°. Roughly speaking, the air weighs twice as much, bulk for bulk, as the hot gases. Naturally, then, the pressure in the chimney is a little less than the pressure of the outside air. Consequently, the air will flow from the place of higher pressure to the place of lower pressure; that is, into the chimney through the furnace.

94. The intensity of the draft, that is, the excess of pressure of the outside air over the pressure existing in the chimney or flue, is measured by means of a water gauge, one form of which is shown in Fig. 26. As will be seen, it is a glass tube open at both ends, bent to the shape of the letter **U**; the left leg communicates with the chimney or flue. The air outside the chimney or flue being heavier, it presses on the surface of the water in the right leg and forces some of it up the left leg; the difference in the two water levels *H* and *Z* in the legs represents the intensity of the draft and is expressed in inches of water.

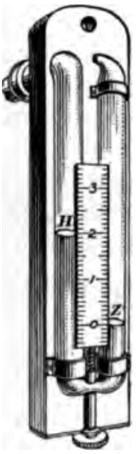


FIG. 26

95. Chimneys and flues that are cold, or have never had a fire connected to them, will usually exhibit a considerable draft. This is due to the fact that the earth constantly warms the air near its surface. Ordinarily, the air thus warmed rises only a short distance before it is cooled and dispersed by convection in the atmosphere, but that which passes up the chimney is protected from convection, and is maintained in an unbroken stream to the top of the stack.

The heat of the earth causes the lower rooms of a house to be warmer than the upper ones. Thus, almost any flue will show a positive current through it, because the temperature is higher at the bottom than at the top.

EFFECTS OF WIND ON CHIMNEYS

96. When the wind blows horizontally, as in Fig. 27, the air that is compressed at *A* flows up over the edge of the chimney and follows the path of the arrows *a* and *b*. This current deflects the wind somewhat, as shown by the arrows *c* and *d*, and lifts it above the leeward edge of the chimney. An opportunity is thus given for the chimney gases (which are shown by feathered arrows) to pass over the edge of the chimney into the area of low pressure at *B*.

As the velocity of the wind increases, the pressure at *B* becomes less, and the chimney draft is augmented correspondingly. If the wind blows upwards, as in Fig. 28, the area of low pressure is formed close to the top of the

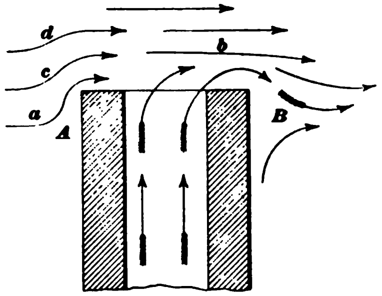


FIG. 27

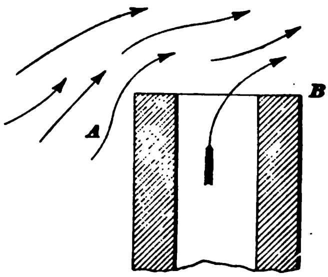


FIG. 28

chimney, as at *B*, and the escape of the chimney gases is greatly facilitated.

If the wind blows downwards, as in Fig. 29, the escape of the chimney gases is cut off, and unless there is sufficient pressure behind them to deflect or lift the wind at the mouth of the chimney, a ***back draft***, or ***blow-down***, will be produced. All that part of the wind that is included between the dotted lines *a* and *b* tends to blow downwards in the chimney, but its

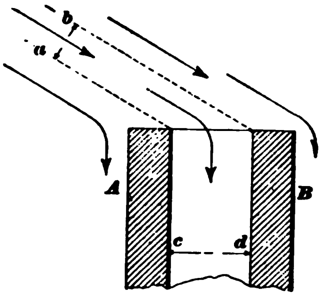


FIG. 29

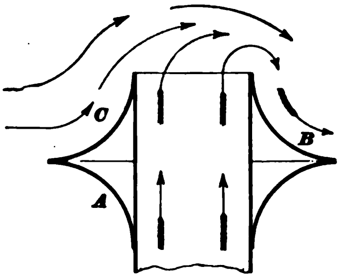


FIG. 30

pressure is reduced as soon as it enters the chimney, because it is then compelled to fill a larger area.

97. The beneficial effect of ordinary horizontal winds on the draft of a chimney may be increased by means of the

circular **deflector** *C* shown in Fig. 30. That part of the wind that is intercepted by the curved surface of *C* is deflected strongly upwards and operates to lift the main current of wind well above the top of the chimney. Thus, the chimney gases are given a good opportunity to escape over the leeward edge, as indicated by the arrows.

The influence of the wind on a chimney is greatly affected by the location of the chimney relatively to the roofs of surrounding buildings.

98. Fig. 31 illustrates the action of the wind on an ordinary inclined roof. The draft of the chimney *A* will be aided by the upward slant of the wind currents, which are caused by the inclination of the roof. The draft of the chimney *B* will be opposed and spoiled by the downward inclination of the wind currents. As the wind passes off the roof to the rear of the house, it will whirl downwards on to the lower

FIG. 31

roof, as shown. These downward currents will interfere seriously with the draft of the chimney *C*, and will in many cases drive the smoke down the chimney and out into the interior of the house. This trouble may be remedied by extending the chimney by means of a pipe and cowl *D*. The outlet for the smoke is thus carried above the region of downward currents.

99. Fig. 32 shows the behavior of the wind when it encounters a large vertical surface, such as the end of a building. The greater part of the current that is intercepted by the wall *a* is deflected upwards, and the draft of the

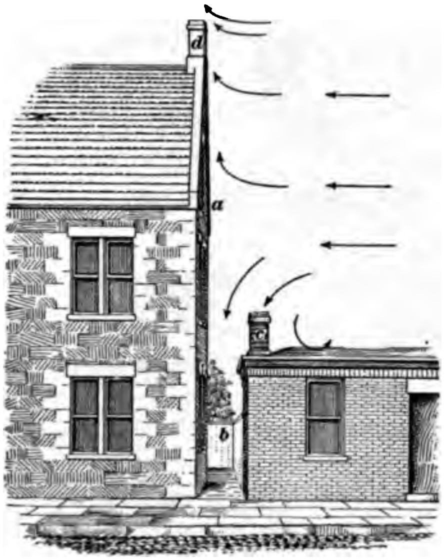


Fig. 32

chimney *d* will be considerably increased. A part of the wind will be deflected downwards into the alleyway *b*, and will cause strong horizontal currents lengthways of the passage. It will also blow downwards into the chimney *c*.

PRINCIPLES OF VENTILATION

(PART 1)

PROPERTIES AND MOVEMENT OF AIR

PROPERTIES OF AIR

CHEMICAL CONSTITUENTS

1. Atmospheric air is composed of several gases that exist independently of each other. They are thoroughly mingled by diffusion, but are not chemically united or combined in any way. The principal gases in air are oxygen, nitrogen, water vapor, or steam, and carbon dioxide, sometimes called carbonic-acid gas, the last forming a very small portion of the whole.

The weight and density of the oxygen and nitrogen are nearly equal; and it is not practicable to separate them by mechanical means. Wherever the oxygen is permitted to go, the nitrogen will accompany it, because no means are known by which it can be held back.

The chemical properties of the gases of which air is composed are very different. Oxygen supports combustion, and is required by all living things to sustain life. Nitrogen, on the contrary, operates to retard combustion, mainly by absorbing heat.

In breathing air, nitrogen is taken into the lungs along with the oxygen. Nitrogen is not known to be of any use to animals, but it is absorbed from the air and converted into useful substances by several varieties of plants, such as peas and beans, and notably by the common red clover.

Pure oxygen may be breathed with impunity, and persons may live in it for a short time without serious harm; but, as the so-called vital energy of pure oxygen is so much greater than that of the air to which the lungs are accustomed, a person breathing oxygen alone will become feverish and intoxicated.

The proportions of oxygen and nitrogen in air vary slightly at times, but not to any important extent. The average composition of 1 pound of dry air is:

	Pound
Oxygen	.2309
Nitrogen	.7687
Carbon dioxide	.0004

Water will absorb more oxygen than nitrogen; consequently, the air that permeates a body of water contains a much larger percentage of oxygen than that in the atmosphere.

In the above statement of the composition of air, the weight of the water vapor, or steam, that always exists in the natural atmosphere is omitted, and the figures given are true only for air that is void of moisture.

WEIGHT AND VOLUME OF AIR

2. The weight of a cubic foot of air at any temperature and pressure may be calculated thus:

Rule.—*Divide the absolute pressure, in pounds per square inch, by .37 times the absolute temperature, in degrees Fahrenheit.*

Or,
$$W = \frac{p}{.37\,T}$$

where W = weight of 1 cubic foot of air, in pounds;
p = absolute pressure, in pounds per square inch;
T = absolute temperature, in degrees Fahrenheit.

Example.—What is the weight of 1 cubic foot of air at a temperature of 60°, the absolute pressure being 14.7 pounds per square inch?

Solution.—Applying the formula,

$$W = \frac{14.7}{.37 \times (460 + 60)} = .0764 \text{ lb. Ans.}$$

3. In Table I, the second column has been calculated by the rule, given in the preceding article, for an atmospheric

pressure of 14.7 pounds per square inch, absolute. The temperatures given in the first and fourth columns of the table are those indicated by the ordinary thermometer; that is, they are not absolute temperatures.

TABLE I

PROPERTIES OF AIR

Thermometric Temperature Fahrenheit	Weight per Cubic Foot Pound	British Thermal Units Given Up by 1 Cubic Foot in Cooling to 0° F. From Temperature in First Column	Thermometric Temperature Fahrenheit	Weight per Cubic Foot Pound	British Thermal Units Given Up by 1 Cubic Foot in Cooling to 0° F. From Temperature in First Column
0	.08637	.0000	75	.07426	1.3228
2	.08600	.0410	80	.07357	1.3979
4	.08562	.0813	85	.07290	1.4716
6	.08526	.1215	90	.07223	1.5440
8	.08489	.1613	95	.07158	1.6151
10	.08453	.2008	100	.07094	1.6849
12	.08417	.2399	110	.06970	1.8209
14	.08382	.2787	120	.06850	1.9523
16	.08346	.3172	130	.06734	2.0792
18	.08312	.3554	140	.06622	2.2019
20	.08277	.3932	150	.06513	2.3204
24	.08208	.4679	160	.06408	2.4352
28	.08141	.5414	170	.06306	2.5461
32	.08075	.6137	180	.06208	2.6541
36	.08010	.6849	190	.06112	2.7582
40	.07946	.7549	200	.06020	2.8596
45	.07867	.8408	210	.05930	2.9576
50	.07790	.9251	220	.05843	3.0532
55	.07714	1.0077	230	.05758	3.1455
60	.07640	1.0888	240	.05676	3.2354
65	.07567	1.1682	250	.05596	3.3228
70	.07496	1.2463	260	.05518	3.4076

4. The volume of air and its weight per cubic foot change with the temperature. The final volume may be computed by the following rule, when the pressure remains constant:

Rule.—*Reduce both the original and final temperatures to absolute temperatures. Multiply the original volume by the final absolute temperature and divide by the original absolute temperature. The quotient will be the final volume.*

Or,
$$V_1 = \frac{V T_1}{T}$$

where V = original volume;
V_1 = final volume;
T = original absolute temperature;
T_1 = final absolute temperature.

EXAMPLE.—What will be the volume of 400 cubic feet of air having a temperature of 150°, when it is cooled to 10°?

SOLUTION.—Applying the rule,

$$V_1 = \frac{400 \times (460 + 10)}{460 + 150} = 308.19 \text{ cu. ft.} \quad \text{Ans.}$$

5. The final weight of a given volume of air may be computed from the following rule, when the pressure remains constant:

Rule.—*Multiply the original weight by the original absolute temperature, and divide the product by the final absolute temperature. The quotient will be the final weight.*

Or,
$$W_1 = \frac{W T}{T_1}$$

where W = original weight;
W_1 = final weight;

and the other letters have the same meaning as in the preceding formula.

EXAMPLE.—A chimney of 1 square foot area and 120 feet high is filled with hot air at a temperature of 450°; the temperature of the atmosphere is 60°; what is the difference in the weight of the air before and after it is heated? The pressure is 14.7 pounds per square inch.

SOLUTION.—The volume of the air is 120 cu. ft. The original weight is (see Table I) $120 \times .0764 = 9.168$ lb., and the absolute temperature is $60 + 460 = 520°$. Then, applying the rule,

$$W_1 = \frac{9.168 \times 520}{460 + 450} = 5.2389 \text{ lb.}$$

The change in weight $= 9.168 - 5.2389 = 3.9291$ lb. Ans.

HEAT CONTAINED IN AIR

6. The number of British thermal units required to change the temperature of a given volume of air at atmospheric pressure can be found as follows:

Rule.—*Multiply together the given volume of air, in cubic feet, the number of degrees Fahrenheit through which it is heated or cooled, and the amount of heat contained in 1 cubic foot of air at the higher thermometric temperature given, as shown in the third and sixth columns of Table I. This product should then be divided by the higher temperature, in degrees Fahrenheit. The quotient will be the amount of heat absorbed or given off, in British thermal units.*

Or,
$$U = \frac{V d c}{t}$$

where U = heat required, in British thermal units;
V = volume of air, in cubic feet;
d = temperature change, in degrees Fahrenheit;
t = higher temperature, in degrees Fahrenheit;
c = constant corresponding to t, taken from Table I.

EXAMPLE.—A current of hot air having a temperature of 150° and a volume of 400 cubic feet per minute is cooled in passing through a certain room to 65°; what amount of heat is given off per minute?

SOLUTION.—From Table I, the heat contained in 1 cu. ft. at 150° is 2.3204 B. T. U. Applying the rule,

$$U = \frac{400 \times (150 - 65) \times 2.3204}{150} = 525.957 \text{ B. T. U. Ans.}$$

7. The number of British thermal units required to change the temperature of a given weight of air at a constant pressure is given by the following rule:

Rule.—*Multiply the specific heat of air, that is, .23751, by the weight of the air, in pounds, and by the difference in the original and final thermometric temperatures, in degrees Fahrenheit. The product will be the amount of heat given off or absorbed, in British thermal units.*

Or,
$$U = .23751\ Wd$$

where U = heat required, in British thermal units;
W = weight of air, in pounds;
d = temperature change, in degrees Fahrenheit.

EXAMPLE.—How much heat is required to raise 250 pounds of air at a constant pressure to 150° F. from 10° F.?

SOLUTION.—Applying the rule,

$$U = .23751 \times 250 \times (150 - 10) = 8{,}312.85 \text{ B. T. U. Ans.}$$

8. By a transformation of the rules in Arts. **6** and **7** it is found that about 55 cubic feet, or 4.2 pounds, of air at atmospheric pressure is raised 1° F. by the application of 1 British thermal unit, or cooled 1° F. by the abstraction of 1 British thermal unit. These values have been calculated for a temperature change between 62° and 63° F., and are convenient values to use in approximate calculations.

EXAMPLES FOR PRACTICE

1. What is the weight of 24 cubic feet of air under 37 pounds absolute pressure at a thermometric temperature of 160° F.?
Ans. 3.871 lb.

2. Suppose that 250,000 cubic feet of air having a temperature of 110° F. is raised 20°; what will the new volume be?
Ans. 258,772 cu. ft.

3. A flue having an area of 2.5 square feet is 60 feet high and contains air at 55° F. at a pressure of 14.7 pounds per square inch. Suppose that this air is heated to 110° F.; how much less will the air in the flue weigh after heating than before heating? Ans. 1.116 lb.

4. What amount of heat is required to raise the temperature of 2,429 cubic feet of air at a pressure of 14.7 pounds per square inch from 10° F. to 140° F.? Ans. 6,340.66 B. T. U.

5. How much heat will be given off by 463 pounds of air in cooling at a constant pressure from 110° F. to 60° F.?
Ans. 5,498.36 B. T. U.

VITIATION OF AIR

DEPLETION OF OXYGEN

9. Air is rendered unfit for breathing by a great variety of causes, that of respiration being the most notable.

Each adult person breathes about twenty times per minute and inhales about 30 cubic inches of air at each breath. The air on entering the lungs contains about 79 per cent., by volume, of nitrogen, and 20.8 per cent. of oxygen, with a very small fraction of carbon dioxide; but, when it is exhaled it contains only about 15.4 per cent. of oxygen, while the carbon dioxide is increased to about 4.3 per cent. of the total volume. The quantity of available oxygen is thus reduced from 20.8 parts to 15.4 parts, or very nearly 26 per cent. The statement is commonly made in technical literature that only about 5 per cent. of the air is taken up by the lungs and applied to the uses of the body, but this mode of stating the facts is misleading, because it fails to convey an adequate idea of the extent to which the air is actually impoverished or vitiated.

The oxygen is the only part of the air (excepting the moisture) that serves to sustain life. The nitrogen is wholly useless, being perfectly inert, and is expelled from the lungs without undergoing any change whatever. It is inhaled simply because it is so thoroughly mixed with the oxygen that its inhalation cannot be avoided. Only about 21 per cent. of the air is of any use for sustaining life; the remainder acts merely in a mechanical way to dilute the oxygen and increase the volume of the mixture. Air that is breathed once thereby loses 26 per cent. of its oxygen; or, in other words, 26 per cent. of its total life-sustaining power.

10. A deficiency of oxygen cannot long be endured by human beings or animals without serious injury; but, on the other hand, an excess of oxygen is not harmful unless the excess be very great. It has been shown by experiment that men can live in pure oxygen for an hour or more at a

time without any serious inconvenience. In recent years, the breathing of oxygen, either pure or mixed with air or medicinal preparations in various degrees, has been employed with considerable success for the cure of certain forms of disease.

If dwelling houses were made air-tight, the trouble from the vitiation of the air by breathing would soon become intolerable; indeed, it would be difficult to maintain life after all the air had once been inhaled. Fortunately, however, walls are generally so pervious that fresh air makes its way inwards with sufficient rapidity to maintain a fair proportion of oxygen to the impurities in the air in the room. This infusion of fresh air, however, may fail to take place in small, dark rooms remote from the open air, and in vaults and subterranean rooms. In such cases, the diminution of oxygen may become a very serious matter.

11. The amount of oxygen consumed per hour varies with the age and state of health of the person, and also with the degree of activity—whether asleep or awake, or engaged in muscular labor. Animals require more oxygen than men.

The amounts of oxygen consumed per pound of actual weight (not per head), are in the following proportions:

Man,	100	Sheep,	117	Dog,	283
Horse,	135	Ox,	132	Chicken,	312

The average adult man consumes oxygen at the rate of about 20 cubic feet per day, the consumption per hour being greater while he is engaged in active labor than when he is quiet or asleep.

INORGANIC IMPURITIES

12. When air is inhaled by the lungs of living creatures, the oxygen absorbed by the lung cells comes into contact with carbonaceous matter derived from the food, and combination takes place, resulting in the formation of carbon dioxide, denoted by the symbol CO_2. The formation of this gas in the lungs is practically continuous, only a

portion being expelled at each breath. This process is one of combustion, and is in every respect the same as that which takes place in a furnace, except that it is less intense. The carbon is supplied at a rate that maintains the temperature at about 98° F. The amount of CO_2 thus produced in 24 hours averages about 16¼ cubic feet for each adult person. Children produce a little less, and sick people often considerably more. The rate of production varies from hour to hour, according to the muscular activity of the individual.

The effect of breathing air containing an unusual amount of carbon dioxide is to check the combustion going on in the lungs, mainly by crowding out the oxygen to a harmful degree. The elimination of carbon from the body then proceeds too slowly, and the result is headache, congestion, and other disorders. If the vital processes are thus checked to a considerable degree, death from suffocation is likely to ensue. If the carbon dioxide is not accompanied by organic or other impurities, air containing 1½ per cent. of it may be breathed for an hour or more without harm, but in most cases it is accompanied by other poisonous compounds that make one-tenth of that proportion hardly endurable.

ORGANIC IMPURITIES

13. The interior surfaces of the lungs and the whole exterior surface of the body exhale moisture continually, although at varying rates. Certain other substances, more or less volatile, are exhaled at the same time. They have an unpleasant odor, especially when abundant, and they decompose very readily, giving rise to odors still more offensive. These emanations have a positively toxic, or poisonous, effect when inhaled. Their exact chemical composition is difficult to determine, but long-continued and careful experiments have made it certain that they cause great discomfort and a feeling of oppression when present in the air in moderate quantities, and that when concentrated they are dangerous.

The quantity of organic matter thus exhaled appears to to bear a definite proportion to the amount of carbon dioxide

produced by respiration in the same time. The ratio is found to be so nearly constant that the precentage of the latter may safely be taken as an index of the quantity of the former existing in the air from the same cause.

Organic emanations from the bodies of persons troubled with indigestion and various gastric and intestinal disorders serve to harmfully pollute the air of dwellings and assembly rooms. The fermentation and decomposition of food give rise to the production of considerable quantities of malodorous gases, some of which are exhaled through the skin, and others through the lungs. The breath then is not only fetid but is liable to be charged with putrefactive germs.

In numerous cases, the breath is also made foul by the odors emitted from decaying teeth, and occasionally a case of nasal catarrh adds its disgusting effluvium to the stream of pollution poured into the air of the room at each respiration. Persons who use tobacco, whisky, or beer, exhale the characteristic odors of these substances through both the skin and the breath, and thus do much to pollute the air around them. Many well-dressed persons permit their clothing to become so saturated with the products of perspiration that they constantly emit rank odors, quite imperceptible to themselves, but very offensive to others.

The peculiar offensiveness of organic impurities in general fully justifies the repugnance that is felt about taking into the lungs the air that has been breathed by others, or mingled, even to a small extent, with the exhalations of their bodies.

DUST AND GERMS

14. The dust found in the air of dwellings, etc. is composed mainly of small fibers of cloth and wood, and minute fragments of various kinds of stone. In thickly populated districts, it is also likely to contain soot and the dried remains of decaying vegetable matter. Such dust is, as a rule, comparatively harmless, merely irritating the nostrils and lungs, but doing no positive injury unless present in large quantities. But, the dust from wagon roads and paved streets is

much filthier in character. In the vicinity of streets paved with stone or asphaltum the greater part of the dust in the air is found to consist of finely pulverized horse dung. Wooden pavements absorb and store up the liquid excreta dropped on them, giving it off again as dust when dried, and as a most loathsome vapor when wetted by summer showers. Of course, such dust as this must be excluded from the lungs at any cost.

15. There is occasionally found in dust an ingredient that deserves close attention; this is the germs of putrefaction and contagious diseases. These germs are microscopic plants that attach themselves to the dust particles, are borne around by them, and are called by the general name of **bacteria.** They are very diverse in appearance, and also in the effects produced by their lodgment and growth. Bacteria may be divided into two great classes: those that flourish only on dead matter—animal or vegetable—and those that thrive only on living animals or plants, and exist at the latter's expense.

The germs of the first class are called *saprophytes;* that is, destroyers of dead things. They break up putrescible matter and reduce it to carbon dioxide, ammonia, and other simple compounds, suitable for the immediate use of ordinary growing plants. The existence of the higher forms of life in this world is believed to depend on the activity of these saprophytes, as without them the plants could not get suitable materials for food, and consequently all animals would die for want of vegetable nourishment.

The germs of the second class are true *parasites;* these are the dangerous ones. When they alight on a living creature, on a part that is both moist and warm, they at once begin to increase and multiply, some kinds slowly, and others with great rapidity. They not only rob the system by absorbing some of the fluids that should nourish the body, but they also produce virulent poisons that derange the system in various ways. Each variety of contagious disease seems to have its own specific form of bacteria, and the disease is

communicated from one person to another merely by transferring the germs of the disease. The germs are carried about in many ways, not only on particles of dust, but also on clothing, books, and everything that may come into contact with the sick person; even pet animals, such as dogs and cats, frequently become the means of disseminating them.

Bacteria are never given off into the air from moist surfaces or liquids, unless the latter are splashed or sprayed. They do not ordinarily pass through the air, except as dry dust. Certain kinds grow in enormous numbers in the slime that covers the inside surfaces of house drains and small sewers, but as long as the slime is kept wet there is comparatively little danger of their being carried into the house by back drafts of air. If a house is closed for any considerable time, and the traps are allowed to become empty, this slime will dry up, and great numbers of bacteria will become detached in the form of dust. It is almost certain that there will be a back draft of air from the sewer into the house in such cases, and that great numbers of the dried germs will then be carried into the rooms. This is probably the cause of the frequent cases of severe sickness that follow the occupation, in the autumn, of houses that have not been occupied during the summer.

SEWER GAS

16. A great many examinations have been made of the air found in sewers and drains, and it is now known positively that there is no such thing as a distinct and peculiar gas that might be called "sewer gas." This term should be understood to mean merely the gaseous contents of sewers, consisting of ordinary air mingled, in varying proportions, with the gases arising from the fermentation and decomposition of sewage. The effect of these gases on persons breathing them in large quantities is to induce asphyxiation and death; in less concentrated form, they cause nausea, diarrhœa, and general prostration. If a small amount is allowed to leak into a house continuously, the

inmates will gradually become debilitated, their power of resisting evil influences becoming less and less, until they fall easy victims to disease.

The danger from sewer gas does not arise solely from the specific disease germs that it may carry, but principally from the poisonous character of the gases it contains. Hence arises the necessity of thoroughly ventilating all sewers and drains, and of preventing the entrance of sewer gas into the building.

GROUND AIR

17. Ordinary soil capable of supporting grass or producing a crop of vegetables is in reality an extensive manufactory of gas. It is here that the myriads of saprophytes, mentioned in Art. **15**, perform their work of decomposing all animal and vegetable remains into elementary substances suitable for the nutriment of living plants. The result of their operation is to produce large quantities of carbon dioxide, together with various ammonia compounds, and, occasionally, sulphureted hydrogen. Free ammonia, however, occurs only in very small quantities.

Carbon dioxide is also produced by the chemical interactions taking place between the mineral substances contained in the soil, the amount varying with the nature of the materials and the degree of moisture.

The production of gas is most copious in soil of moderate moisture; very dry earth produces but little. When the soil is constantly saturated with water, the processes are different, and the quantity of gas evolved is usually smaller.

The atmosphere penetrates the ground to a considerable depth, but its composition undergoes a great change as the depth increases. The extent of the change varies, of course, with the local conditions. At a depth of only a few inches in good ordinary soil, the air permeating it is found to contain from about 7 to 10 per cent. of oxygen, instead of the 21 per cent. present in normal air. The proportion of carbon dioxide existing at the same time is, on an average, about 7 per cent. In very dry, barren soil, too poor to support

vegetation, the proportion has been found as low as $\frac{1}{5}$ of 1 per cent., while in very rich meadow land, as high as 14 per cent. has been measured.

The ground appears to be the source of the carbon dioxide that pervades the atmosphere. The amount produced by the respiration of men and animals is extremely insignificant in comparison with that which constantly exudes from the soil.

Air taken from a height of 2 inches above the surface of the ground shows a larger percentage of the gases known to be generated in the soil than at a height of 5 or 6 feet, while the difference between air taken at the latter level and at a height of 40 or 50 feet is barely perceptible. The normal atmosphere contains about $\frac{1}{25}$ of 1 per cent. of carbon dioxide, or about 4 parts in 10,000.

It will readily be perceived, therefore, that the air which permeates the ground, or lies in contact with it, is quite unfit for breathing, and when it is remembered that the soil around dwellings is very liable to be poisoned by the leakage from gas mains, house drains, privy vaults, etc., it becomes very clear that ground air should be carefully excluded from the heating and ventilating system.

CELLAR AIR

18. Any excavation in the earth, such as a cellar, trench, or well, acts as a vent for the gases contained in the adjacent soil. They ooze through the sides and bottom, and gradually fill up the well, etc., precisely as water will fill a hole that is made in wet ground. The extent to which such gases will accumulate in such places depends on the facilities that are given them to escape and diffuse in the atmosphere. In the case of a deep well, the opening into the free air is small, and gas is apt to accumulate in sufficient proportions to quickly suffocate any person descending into it; whereas, in a wide open pit of equal depth, the gas will pass into the atmosphere so freely that only an insignificant difference can be found in the air at the top and at the bottom.

Ordinary cellars act as collecting basins for these earth gases; and unless adequate ventilation is provided they will pass through the floor and diffuse in the rooms above. The inflow of gas cannot be stopped by facing the walls or bottom of the cellar with Portland cement, because gases will pass through ordinary brick, mortar, and cement about as readily as water will percolate through a stratum of fine sand. The cement will serve to retard the flow somewhat; but, in order to stop it, substances like asphaltum or paraffin must be used.

19. A prolific source of pollution in the air of cellars is found in the practice of using them to store supplies of fruit, vegetables, and coal. Potatoes and cabbages give off a considerable quantity of gas and rank odors, which are debilitating to persons who inhale them to any extent. Apples also impair the quality of the air around them, although their odor may be quite agreeable. Coal always emits gas when exposed to air, although while the coal is perfectly dry the amount is unimportant; but, when the coal is put in the bin dripping wet, it oxidizes so rapidly that the amount of gas given off is highly deleterious. The custom of wetting the coal supplied to dwellings, etc., merely to keep down the dust while being handled, is a pernicious one and should be discouraged.

AIR ANALYSIS

INDEX OF VITIATION

20. To make an analysis of air, with a view to discovering the proportions of carbon dioxide and other impurities in it, is properly the work of an experienced chemist. An amateur cannot reasonably expect to secure very accurate results, because accuracy depends, in great part, on the skill and care taken in handling the apparatus, and in preparing the materials. With a little practice, however, and a few lessons from some practical chemist accustomed to dealing with gases, sufficient accuracy for ordinary practical purposes may be acquired.

Although CO_2 is not the most dangerous impurity, yet the amount of it present in excess of that contained in the outer atmosphere is known to very accurately denote the degree of vitiation, and the vitiation is usually designated by the number of parts of CO_2 in each 10,000 parts of air.

The proportions of CO_2 likely to be found in the air of inhabited buildings will range from 2 to 20 parts in 10,000 in excess of the quantity normally present in the atmosphere; and all analyses must be accurate to within at least 1 part in 10,000 in order to be of practical value.

Numerous instruments have been devised and put on the market to indicate the presence of CO_2 in a sample of air, by an exposure of a few minutes; and others have been constructed to indicate the proportion continuously, just as a thermometer indicates temperature. These instruments are useful in making approximate determinations of CO_2, and are not intended to take the place of an exact chemical analysis.

The proportions of the other impurities, such as carbon monoxide, ammonia, or organic matter, can be determined only by methods that require the skill of an experienced chemist.

TAKING SAMPLES OF AIR

21. In order to secure a sample of air, a gas bag is generally employed. The bag is rolled up tight, or otherwise compressed to insure its emptiness, before it is taken into the room where the sample is to be taken. In taking the sample at the place desired, great care must be exercised to avoid taking in an undue share of the breath exhaled by the operator. Persons must not be allowed to stand around the apparatus to see what is going on; on the contrary, they should all be required to remain in their places, or at least to keep some distance away. The analyses are liable to yield amazing results if this precaution is neglected.

If a pump is used to fill the bag, the pumping should be stopped before any pressure is put on it. If the air is put under pressure, the CO_2 is liable to leak out by soaking through the fabric; and the same thing is liable to occur if

the bag is allowed to lie a long time before the contents are examined. No bag that has held any other kind of gas should ever be used for the purpose of testing samples of air.

The best way to conduct analyses of air in buildings, although not always the most convenient, is to set up the analyzing apparatus in the room to be examined, and to take the air in through clean tubing when necessary.

AIR-TESTING APPARATUS

22. Fig. 1 shows a simple apparatus for detecting the presence and determining the quantity of carbon dioxide in a sample of air. A vessel *A* of known capacity is filled with a sample of the vitiated air, by first filling it with water, and then placing it in the suspected air and emptying the water out of the jar, when the air will take its place. A saturated solution of caustic soda, having been prepared and stored in the bottle *B*, is then poured slowly into the funnel-mouthed tube *D* from which it flows into the bottom neck *C* of the jar, stopping when the surface of the liquid in *D* is at the same height as that in *C*. The caustic soda in the water greedily absorbs the carbon dioxide in the air contained in *A* and combines with it to form carbonate of soda. This absorption causes a partial vacuum in the jar *A*; hence, the liquid rises in *C*, and the volume of the liquid around *D* between the lines *a* and *b* will equal the volume of carbon dioxide extracted from the sample of air if the pressure in *A* equals that of the atmosphere, that is to say, if the water-line within the tube is level with that around it. If so much liquid has been poured that the water-line in *D* is above the

FIG. 1

water-line *b*, the air in *A* will be compressed and the water-line *b* will rise higher than it should; consequently, the volume of the liquid in *C* that is meant to represent the exact volume of carbon dioxide taken from the air in *A* will be too great. If too little liquid is poured in, the water-line in *D* will fall below the water-line *b*, and therefore it follows that the air in *A* would be subjected to tension and the water-line *b* would be lower than it should; consequently, the volume of the liquid representing the volume of carbon dioxide in the sample of air would be too small. Owing to the small area of the surface of the liquid exposed to the sample of air in the jar, the chemical change is liable to be slow; but, if the jar is shaken horizontally, thereby agitating the liquid in *C*, the chemical change will be more rapid. Suppose that the volume of *A* is 500 cubic inches, and that at the end of a test the liquids in *D* and *C* are level and the volume of the liquid rising in the neck *C* is 1 cubic inch, that is to say, the volume of carbon dioxide extracted from the air in *A* is 1 cubic inch, it will be seen that the quantity of carbon dioxide in the sample is $\frac{1}{500} = .002 = .2$ per cent., or, in other words, 2 parts per 1,000 or 20 parts per 10,000 volumes. Deducting the quantity of carbon dioxide that the air holds in its natural state (about 4 parts in 10,000), there are $20 - 4 = 16$ parts per 10,000 as the vitiation due to exhalation, etc.

FIG. 2

23. A simple and sufficiently accurate method for ordinary tests consists in the use of the Doctor Fitz apparatus illustrated in Fig. 2. Here a glass tube *a* surrounded by another *b* and having a rubber sleeve *c* to prevent the leakage of the contents, is so arranged that by slipping up the inner tube a certain volume of the room air may be trapped, or enclosed. The thumb is then placed over the end and a known volume of a colored liquid (phenol phthalein) previously introduced is well shaken. This liquid can be

bought from any dealer in chemicals. The outer tube is then slipped down, releasing the air, and the process is repeated again and again, note being taken of the number of volumes of air brought into contact with the liquid. This is done until all color disappears from the latter. A table accompanying the apparatus shows the number of parts of CO_2 corresponding to the volume of air required to cause the color to disappear.

24. The following method of testing air is one that is generally known and that is sufficiently convenient and accurate to be recommended in connection with ventilating operations. The process is based on the fact that a solution of caustic potash will absorb carbon dioxide without affecting the other constituents of the air. For use in this connection, the solution must be *saturated*, and the chemicals must be pure.

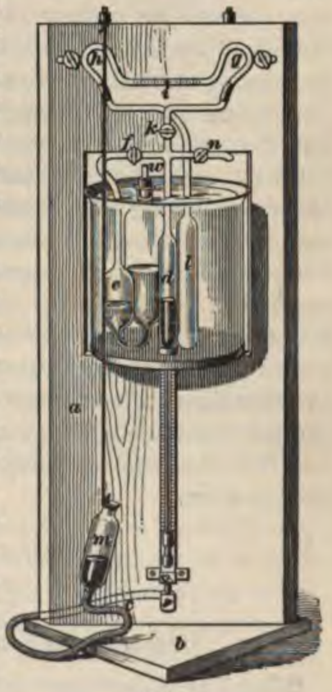


FIG. 3

The apparatus is shown in Fig. 3, and can be readily obtained from any dealer in chemical supplies. The parts of the apparatus are secured in place within openings made in the vertical board *a*, and stability is afforded by the square base *b*. The apparatus consists of a vertical glass tube *d* that is graduated throughout the greater part of its length, and a **U**-shaped bottle or burette *e*, connected to *d* by a stop-cock *f*. A small pressure gauge *g h*, having a drop of liquid moving along a graduated scale *i*, is connected to *d* by means of the stop-cock *k*. The other end of the gauge tube is connected to an air chamber *l*. The flask *m* is connected

to the base of the tube *d* by the rubber tube *c*, and is designed to act as a pump. Both *m* and *d* are partly filled with mercury, and the contents of the latter are expelled by raising the flask *m* until the mercury rises to the top of the chamber. The air to be tested is then drawn in through the cock *n* by lowering the flask, the mercury in *d* being lowered to the zero of the scale. The cocks *f*, *n*, *k*, *g*, *h* being open, the position of the index *i* is noted, and all the cocks are now closed except *f*. The flask *m* is then raised until all the air is drawn from *d* over into the burette *e*, which is filled half full with a saturated solution of pure caustic potash, through the stopper *w*. This substance quickly absorbs the CO_2, and thus reduces the volume of air under examination. The air is shifted back and forth from *d* to *e* several times, being finally drawn back into *d*, and the stop-cock *k* to the pressure gauge opened. The flask is next raised or lowered until the index *i* stands at the point previously observed. It will then be seen that the mercury stands higher in *d* than before, showing that absorption has taken place. The amount thus absorbed can be read off on the scale, the graduations indicating the proportion in ten thousandths of the volume of the air in the apparatus. As nothing but CO_2 is absorbed, no further treatment or computation is required. A vessel containing water usually surrounds the parts *l*, *d*, and *e*, to maintain a uniform temperature. If the temperature of the sample is changed, the indication of the pressure gauge *i* will be affected by the expansion or contraction of the air under examination.

HUMIDITY OF AIR

PROPERTIES OF AQUEOUS VAPOR

25. The water vapor that pervades the atmosphere exists in the form of a gas independent of the oxygen and nitrogen, but being a compound gas its properties differ somewhat from those of a simple gas. Thus, it condenses into water at 212° under a pressure of 14.7 pounds per square

inch, while oxygen and nitrogen become liquids only at extremely low temperatures and under enormous pressures.

But steam does not condense entirely and completely into water under atmospheric pressure at the temperature of 212°; a part of it remains in the gaseous condition as true steam, even though its pressure should fall below that of the atmosphere. Steam exists at all temperatures down to zero, and even many degrees below. Thus, at 20° below zero, and under an absolute pressure of .008 pound per square inch, as shown by Table II, steam still exists. Under natural conditions, the atmosphere is never free from the presence of steam, or vapor of water. The absolute pressure of this steam is very low, but it forces its way into the space occupied by the other atmospheric gases, and increases the total tension of the atmosphere by the amount of its own pressure.

The aggregate tension of the gases that constitute the atmosphere is shown by the barometer, but no instrument has yet been devised that will show the actual tension of any single one of these gases; therefore, the pressure of atmospheric steam cannot be measured directly, except by apparatus that cannot be conveniently used outside of the laboratory.

A cubic foot of air will admit or take up the same quantity of steam as a cubic foot of empty space. The weight of the steam will depend solely on the temperature, provided that it does not become superheated. The temperature to be considered is that at which condensation begins.

26. The quantity of steam should always be measured by its weight, as given in Table II. The weight of a cubic foot of saturated steam increases with the temperature, while the weight of air decreases as the temperature rises, because the air is expanded. Steam will always have the weight given in the table, unless it is shut off from all communication with water and is superheated. The pressure and weight increase simultaneously, but at different rates; consequently, the pressure should not be taken as an index of the quantity of the steam.

The ratio between the quantity of vapor, or atmospheric steam, actually present in the air, and the maximum quantity it could contain at the temperature and barometric pressure then prevailing, is called the **humidity** of the air.

TABLE II

PROPERTIES OF AQUEOUS VAPOR

Temperature Degrees Fahrenheit	Pressure per Square Inch Pound	Weight per Cubic Foot Pound	Temperature Degrees Fahrenheit	Pressure per Square Inch Pounds	Weight per Cubic Foot Pound
−30	.0049	.000017	50	.176	.00058
−25	.0063	.000023	55	.212	.00069
−20	.0088	.000030	60	.253	.00082
−15	.0106	.000039	65	.302	.00097
−10	.0135	.000050	70	.358	.00115
− 5	.0171	.000063	75	.425	.00135
0	.0216	.000079	80	.502	.00158
5	.0272	.000098	85	.589	.00183
10	.0340	.000121	90	.692	.00213
15	.0423	.000149	95	.809	.00247
20	.0525	.000181	100	.943	.00286
25	.0651	.000222	105	1.094	.00330
30	.0806	.000270	110	1.265	.00380
35	.0998	.000325	115	1.462	.00433
40	.1225	.000400	120	1.682	.00496
45	.1470	.000480	130	2.213	.00640

27. When the atmosphere contains the maximum quantity of steam that can exist at the temperature of the air, it is said to be **saturated** with moisture.

During fair weather, the quantity actually present is much below the maximum that the temperature of the atmosphere will permit. When the maximum is reached, the least diminution of temperature or barometric pressure will be followed by the condensation of a part of the vapor. The

condensed vapor will be precipitated as dew or rain during summer weather, or as snow in winter time, and in very cold weather it will appear as hoarfrost.

EFFECT OF HUMIDITY

28. The presence of moisture in the atmosphere affects it in three ways: first, by diminishing its weight per cubic foot, thus making it more buoyant; second, by increasing its capacity for heat, making it more effective for either heating or cooling purposes; and third, by reducing the amount of oxygen contained in a cubic foot, thus impairing its value for purposes of respiration. Table III shows the weight per cubic foot of pure dry air and the weight of air displaced by moisture; also, the maximum amount of moisture, in grains per cubic foot.

TABLE III

EFFECT OF MOISTURE ON AIR

Temperature Degrees Fahrenheit	Weight of 1 Cubic Foot of Dry Air Pound	Weight of Air Displaced by Vapor Pound	Weight of Moisture in 1 Cubic Foot of Saturated Air Grains
10	.08453	.0002	.776
20	.08277	.0003	1.235
30	.08108	.0005	1.935
40	.07946	.0007	2.849
50	.07790	.0010	4.076
60	.07640	.0014	5.745
70	.07496	.0019	7.980
80	.07357	.0027	10.934
90	.07223	.0036	14.790
100	.07094	.0048	19.766
110	.06970	.0063	26.112
120	.06850	.0083	34.115

The amount of moisture contained in the atmosphere has a considerable influence on the health and comfort of persons

who live in it; this point, then, is one of great importance in dealing with questions of ventilation.

29. Ordinarily, the sense of feeling cannot be trusted in forming an estimate either of the real temperature or of the humidity of the surrounding air. Sensations of warmth and coolness, in air of moderate temperature, depend very largely on the amount of evaporation going on from the body. When the atmosphere is dry, water is evaporated freely, both from the lungs and skin, and persons feel cool and comfortable; but if the air is quite humid, the rate of evaporation is much slower, the heat generated within the body tends to accumulate, and persons become oppressively warm. They drip with perspiration, because the air is already so full of moisture that it will not take up the water as fast as it is exuded from the skin; consequently, it accumulates in the form of sweat.

Thus, air at 90°, if very nearly dry, will feel fresh and invigorating; but if the humidity be increased 50 per cent., it will seem hot and very sultry, and if it approaches saturation, the air will become very oppressive and exhausting. As the temperature remains the same in each case, it is clear that the difference in the effects is due solely to the change in humidity.

A climate having a temperature of 100° or more for months at a time can be endured without any special discomfort so long as the humidity is low. But, if the moisture increases to a degree approaching saturation, even people of strong physique will rapidly languish under the influence of an atmosphere continually surcharged with moisture.

Dry air at 40° is very fresh and agreeable, if proper clothing is worn; but if it is nearly saturated with moisture it will feel very chilly, and the cold will be penetrating.

30. The comfort of an audience gathered in a church or hall depends largely on the humidity prevailing in the room. The temperature may fall to 60° without much complaint, so long as the air is kept dry; but, if the humidity is allowed to rise, the complaints of cold will be both numerous and

emphatic. On the other hand the temperature may rise to 75° without exciting remark, the air, as long as the humidity is not above 20 per cent., appearing delightfully fresh and pure; at 35 or 40 per cent., the audience will feel about as warm as they care to be; while, if the humidity rises to 60 or 70 per cent., they will fairly swelter with heat. Thus the variation of temperature from 60° to 75° will attract very little attention if the air remains dry; but if the humidity is allowed to rise considerably, this change in temperature will make all the difference between the conditions of chilly and unbearably warm. This explains the failure of the attempts that have often been made to cool the air of large audience rooms, in summer time, by passing it over wet screens or through a spray of water. Although the air was slightly reduced in temperature, the humidity was increased, at the same time, to such an extent that its effects not only neutralized the fall in temperature but made the air less comfortable than before.

31. A high degree of humidity is not desirable in any case for air that is to be breathed. European engineers recommend for dwellings, etc., that the humidity be made 60 to 70 per cent. But, the climate of the United States of America is so different that a lower rate must be employed. Extensive observation shows that in the latter country the humidity should be from 30 to 40 per cent. of saturation. As a general rule, the air in an apartment may be considered sufficiently humid so long as no irritation of the eyes or throat becomes noticeable.

32. The proportion of oxygen in the atmosphere is reduced somewhat by the presence of moisture in it. Usually the loss is so small that it may be neglected, but under some circumstances it becomes large enough to require consideration. By referring to Table III, it will be seen that a cubic foot of perfectly dry air at 70° weighs .07496 pound, while the amount of pure air (that is, dry oxygen and nitrogen) to be found in the same volume of saturated air is only .07306 pound, the difference, .0019 pound,

having been displaced by the vapor or steam. Thus, the air loses 19 parts of its oxygen, etc. out of nearly 750 by becoming saturated; consequently, its respiration value is reduced $\frac{19}{750}$, or about $2\frac{1}{2}$ per cent. In a similar manner, air at 100° loses about $6\frac{1}{2}$ per cent. of its value for breathing purposes when saturated with moisture.

This deterioration of the atmosphere by the presence of moisture in excessive amounts is often very plainly felt during hot summer weather, just before a storm. At such times the humidity approaches saturation, and the deficiency of oxygen is so great that people sometimes pant for breath. The evaporation from the surface of the body is greatly diminished, allowing the bodily heat to accumulate, and this adds to the feeling of depression and distress. The same thing is liable to occur in laundries, cooking rooms, dye houses, and other places where both the temperature and humidity are high.

33. Atmospheric steam or water vapor is much lighter than air at the same temperature; consequently, any mixture of vapor and air is lighter than pure dry air. The belief that damp air is necessarily heavy, and therefore inclined to sink to the bottom, is wholly erroneous. In those cases where it is seen to gravitate downwards, it will be found that the movement is due to the fact that its temperature is considerably lower than that of the surrounding atmosphere. A difference in the humidity, at various levels, of a body of air having a uniform temperature throughout, will cause circulation, precisely as a difference in temperature will do.

The circulation that takes place in a ventilating stack in summer time is largely aided by the humidity of the air at its base. The interior of a house is apt to be more humid, especially in the lower stories, than the atmosphere at the top of the stack. The steam jets that are sometimes used at the base of a stack to increase the draft owe part of their effectiveness to the humidity they impart to the rising column of air, making it lighter than it would otherwise be.

The air in kitchens and laundries is not only warm but also quite humid; consequently, it is exceedingly buoyant. This partly explains the strong tendency evinced by kitchen odors, etc. to ascend and pervade the upper parts of the house.

MEASUREMENT OF HUMIDITY

34. There are many substances that absorb moisture from the atmosphere and swell in volume in consequence. Many attempts have been made to utilize this property, to construct instruments that would indicate the density of the moisture in the air. The most successful instrument of this kind is shown in Fig. 4. The indicator hand is attached to a metallic spiral that is filled with absorbent material. This material absorbs moisture from the air in proportion to the density of the atmospheric vapor, and gives it off again as the density decreases. The material swells in proportion to the amount of moisture it holds, and thus the spiral that contains it is compelled to bend, like the Bourdon tube in a steam gauge.

FIG. 4

35. The humidity of the atmosphere may be measured by means of two thermometers, one of which is perfectly dry, and the other provided with a wet cloth over its bulb. The cloth is kept moist by a thread or wick leading from a small tank. If the air is not saturated, the water will evaporate from the cloth and thus cool the bulb. The rapidity of the evaporation depends on the relative dryness of the air, and the depression of the thermometer indicates approximately the rate of evaporation from the cloth. This device is called the **wet and dry bulb thermometer.**

The scale of humidity is arbitrary, and the operation of the instrument is not sufficiently accurate to be satisfactory.

36. The humidity of the atmosphere may be accurately measured by observing the temperature at which the contained moisture or vapor will condense. Having found the temperature at which condensation takes place, the pressure of the vapor per square inch and its weight per cubic foot may be found from Table II.

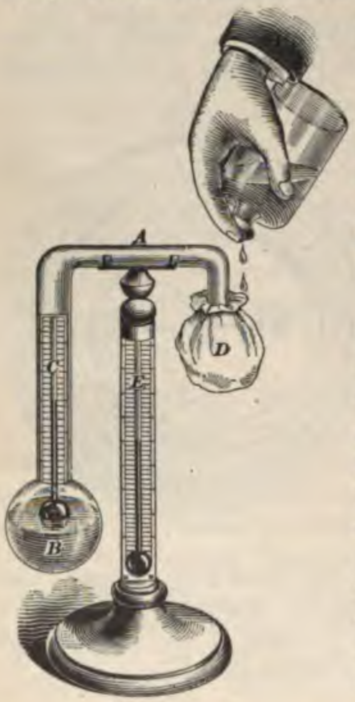


FIG. 5

The weight of the moisture said to be *absorbed* by a cubic foot of air is the weight of a cubic foot of vapor at the pressure and temperature thus found.

The instruments commonly used for the purpose of determining the temperature at which the aqueous vapor will condense are called **dew-point hygrometers.** They operate by gradually cooling a bulb or plate of black glass below the atmospheric temperature. As the temperature falls, a point will be reached when a deposit of dew begins to appear on the glass. The formation of dew signifies that the atmospheric vapor actually present condenses at the temperature the glass then possesses. Black glass is preferred, because it readily shows the slightest film of dew.

37. Daniell's hygrometer is shown in Fig. 5. It consists of a glass tube A having a bulb at each end, as shown. The bulb B is made of black glass, and is partly filled with sulphuric ether. The bulb D is empty and is covered with muslin. A small mercurial thermometer C is

enclosed in the tube *A*, and is so suspended that its bulb extends below the surface of the liquid ether. This thermometer indicates the temperature of the liquid in the bulb *B*. A second thermometer *E*, attached to the wooden stand, indicates the temperature of the surrounding air. To operate the instrument and obtain a deposit of dew on the bulb *B*, a small quantity of ether is poured over the muslin on the bulb *D*. The ether evaporates rapidly, and thus absorbs heat from the bulb and the ether vapor contained in the instrument. As the temperature falls, a point will be reached when a deposit of dew will appear on the surface of the bulb *B*. The dew will remain there until the ether wholly evaporates from the muslin covering of *D* and the instrument begins to recover its normal temperature.

If too much ether is poured on the cloth-covered bulb *D*, the instrument may be cooled to such an extent as to depress the thermometer *E* and cause it to give a false indication of the temperature of the atmosphere.

The temperature shown by the thermometer *C* at the exact moment when the dew appears and disappears must be carefully noted. If there is much difference in the first and second readings, the test should be repeated. When the test is properly made, the average of the two readings may be taken as the correct dew point.

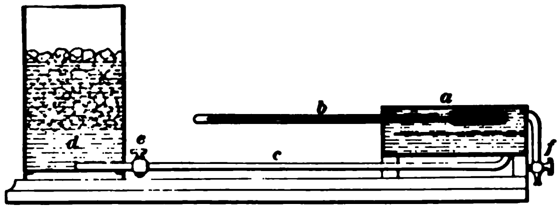


Fig. 6

38. Dines' hygrometer is shown in Fig. 6. It consists of a small metal box or chamber having a top plate *a* of thin black glass. The bulb of a thermometer *b* is placed close to the under side of the glass, but not in contact with it. The box is kept full of water by means of a pipe *c* that extends

to a small tank of ice water d. When the cock e is opened, the water flows through the box and escapes at the waste pipe f.

To ascertain the dew point, the box is first filled with water having about the same temperature as the air. Then ice water (or lumps of ice and water) is placed in the tank d; the cock e is then opened enough to permit a small stream of cold water to pass into the box and mingle with the water which it contains. When the water is cooled to the dew point, a deposit of dew appears on the surface of the glass a. The cock e is then closed and the box allowed to recover its normal temperature. As the temperature rises, the dew will vanish. The temperatures indicated by the thermometer b at the exact moments when the dew appears and disappears should be carefully noted. The temperature of the air should be measured by an independent thermometer.

39. To make a measurement of humidity, the instrument should be placed in a position where it will be free from the influence of any heating agency. The operator should take care that the warmth of his hands or breath does not affect the thermometers. Then use the following:

Rule.—*Having found the dew point, ascertain from Table II the weight of a cubic foot of vapor at that temperature; this divided by the weight of a cubic foot of vapor at the temperature of the atmosphere expresses the relative humidity.*

Or,

$$A = \frac{a}{b}$$

where A = relative humidity;

a = weight of vapor per cubic foot at dew point, in pounds;

b = weight of vapor per cubic foot at temperature of atmosphere, in pounds.

Example.—What is the relative humidity when the temperature of the atmosphere is 70° F. and the dew point is found to be at 45°?

Solution.—From Table II, the weight of 1 cu. ft. of vapor at 45° is .00048 lb. The weight of 1 cu. ft. at 70° is, from the same table, .00115 lb. Hence, applying the rule, $A = \frac{.00048}{.00115} = .417 = 41.7$ per cent. Ans.

MOISTENING AIR

40. It is very necessary that air which is to be breathed should contain a proper amount of moisture. If the air in a room is too dry, it will have an irritating effect on the lungs of the person breathing it. The moisture that naturally exudes from the lungs and skin will be evaporated with undue rapidity, thus interfering with the proper operation of the lungs, and making respiration uncomfortable. The unnatural dryness of the skin gives rise to considerable nervous irritation, which, if long continued, will seriously affect the general health.

The air in inhabited rooms is usually maintained at a temperature of 65° to 70° F.; therefore the dew point, as measured by the hygrometer, should be about 55°. If the dew point is too high, there will be an unpleasant feeling of dampness in the air, the window panes will drip with moisture, and there will be a deposit of dew on all objects in the room having a temperature lower than the normal.

If there is a great difference in temperature in the upper and lower parts of the room, the humidity should be adjusted to suit the zone in which the people breathe.

41. The amount of water that must be evaporated and added to the air supply to maintain any desired degree of humidity may be found as follows:

Rule.—*Ascertain the weight of moisture in the air before it is heated, and compute the weight of moisture required to produce the desired degree of humidity in the same weight of air at the temperature at which it is to be used; the difference between the quantities of moisture thus found will be the amount of moisture to be supplied.*

EXAMPLE.—A certain room is supplied with air having a temperature at the registers of 120°, at the rate of 300 cubic feet per minute. The temperature of the room is to be maintained at 70°, and the humidity at 70 per cent. The temperature of the air before entering the heater is 45°, and its humidity is also 70 per cent. What weight of moisture must be supplied to the air-current to secure the desired humidity in the room?

Solution.—It is necessary to know the volumes of the air at the time it is used and before it enters the heater, and these must be computed from the volume and temperature at the register as given. The original volume is 300 cu. ft. and the original temperature is 120° (580°, absolute). Applying the rule in Art. 4 to find the volume at 70° (530°, absolute),

$$V_1 = \frac{300 \times 530}{580} = 274.1 \text{ cu. ft.}$$

and at 45° (505°, absolute),

$$V_1 = \frac{300 \times 505}{580} = 261.2 \text{ cu. ft.}$$

Thus, at the beginning there are 261.2 cu. ft. of cold air at 70 per cent. humidity. The weight of that volume of vapor at 45° is, from Table II, $261.2 \times .00048 = .1254$ lb., and 70 per cent. of this equals $.1254 \times .70 = .08778$ lb., which is the weight of moisture originally contained in the air.

The air when used will have a volume of 274.1 cu. ft. and a temperature of 70°. The weight of an equal volume of vapor at 70° is $274.1 \times .00115 = .3152$ lb. The humidity is required to be 70 per cent.; therefore, the total moisture required will be $.3152 \times .70 = .22064$ lb.

Then, $.22064 - .08778 = .13286$ lb. is the amount of moisture per minute that must be added to the air-current. Ans.

42. It will be observed from the example in Art. **41** that the quantity of water required to maintain any certain degree of humidity is much greater for warm air than for cold. The amount increases faster than the temperature. Table II shows that the increase of moisture per cubic foot for a rise in temperature from

−10° to 0° is .000029 pound
30° to 40° is .000130 pound
80° to 90° is .000550 pound

Thus, the increase between 80° and 90° is nearly nineteen times as much as between −10° and 0°

Inasmuch as the space into which water evaporates is usually occupied by air, and as the temperature of the air determines the temperature of the vapor, it is natural to speak of the capacity of the air for vapor. This is really a misleading expression, like many others inherited by science from the obscurity of earlier years. The idea that air absorbs moisture as a sponge absorbs water is entirely erroneous.

The vapor forces its way into space solely by virtue of its expansive power. The amount that will enter any given space depends only on its own temperature, and it is not affected by the presence or absence of other gases in the same space.

The terms commonly used to describe the phenomena of atmospheric vapor are so firmly fixed by long usage that they cannot be easily changed. Much obscurity and perplexity may be avoided, however, by fixing the real meaning of the terms clearly in the mind.

43. The methods commonly used for moistening air consist in passing it through a spray of water, or over the surface of water contained in evaporating pans, or by injecting steam into the air-current.

A great many devices have been invented for projecting water into the air-current in the form of finely divided spray. A favorite device is a fan having water jets attached to the blades, water being supplied through the fan shaft, which is hollow. These machines serve to load the air with water, but the water is held only in mechanical suspension, instead of being evaporated and transformed into steam. They are useful for dampening materials in process of manufacture, such as cloth, paper, tobacco, etc.; but they are wrong in principle when used for humidifying air for ventilating purposes.

It is at this point that the old delusion that air actually absorbs moisture becomes very misleading. Air cannot be wetted, although it can be made to carry water some distance by entrainment. It should be clearly understood that the problem of humidification is to make steam, and that this can be done only by evaporation. The quantity of steam to be made must, when added to that already existing in the atmosphere, be fully equal to the volume of the air-current, and its pressure or density must be that corresponding to a boiling point of about 40° F., that is, the desired dew point of the air when delivered.

The heat required for evaporation is frequently absorbed from the air-current.

The weight of steam discharged into the atmosphere, per hour, through jets of small diameter, the pressure being not lower than about 20 pounds per square inch absolute, is about as follows:

Orifice $\frac{1}{32}$ inch diameter = .03944 pound
Orifice $\frac{1}{16}$ inch diameter = .15770 pound

At lower pressures, the rate of discharge becomes slower.

EXAMPLES FOR PRACTICE

1. The dew point being 50° F., and the temperature of the air 85° F., what is the relative humidity? Ans. 31.69 per cent.

2. If 25,000 cubic feet of air, per hour, enters a room at a temperature of 130° F., what weight of moisture must be added to keep the humidity in the room at 65 per cent., when the temperature of the room is to be 75° F., and the air before entering the heater has a temperature of 50° F. and a humidity of 70 per cent.? Ans. 11.12 lb.

MOVEMENT OF AIR

METHODS OF MOVING AIR

44. Movement of the air required for purposes of ventilation and also for heating is accomplished by natural means or **natural draft**, or by mechanical means or **forced draft**.

In both systems, the power employed to move the air is derived from heat. In the former system, it is applied directly to the air to expand it and reduce its weight, so that the colder and heavier atmosphere will displace the warmer air and drive it through the flues, as desired. In the latter system, the heat is first converted into work through the agency of a boiler and engine, and is then applied to moving the air by means of a fan. Of course, the conversion of heat into work is attended with considerable loss; but after making all proper allowances for imperfections of machinery, etc., it is found that, in order to move a given quantity of air, the former system requires very much more heat than the latter.

This is illustrated by the following table, which was prepared by Prof. R. C. Carpenter, to show how many times the forced-draft, or fan, system of ventilation is more efficient than the natural, or gravity, system of securing a movement of air in ventilating flues:

TABLE IV

COMPARISON OF NATURAL-DRAFT AND FAN-DRAFT SYSTEMS

Height of Flue Feet	Temperature of Air in Flue. Degrees Fahrenheit						
	80	100	150	200	250	300	400
	Number of Times Fan Is More Efficient Than Vertical Ventilating Chimney or Flue						
10	68.4	73.4	87.3	102.0	118.0	135.0	173.0
20	34.2	36.7	43.6	51.0	59.0	67.0	86.0
30	22.8	24.5	29.1	34.0	39.0	45.0	57.0
40	17.1	18.3	21.8	24.0	29.0	34.0	44.0
50	13.7	14.7	15.4	20.0	24.0	27.0	35.0
60	11.4	12.2	14.5	17.0	19.0	22.0	28.0
70	9.8	10.5	12.8	15.0	17.0	19.0	25.0
80	8.5	9.2	10.9	12.0	15.0	17.0	22.0
90	7.6	8.1	9.7	11.0	13.0	15.0	17.0
100	6.8	7.3	8.7	10.0	12.0	13.5	15.3
125	5.4	5.9	7.0	8.1	9.5	10.0	13.9
150	4.6	5.1	6.1	6.7	8.0	9.0	11.7
175	3.9	4.2	5.0	5.8	6.7	7.7	9.9
200	3.4	3.6	4.4	5.1	6.0	6.7	8.6
250	2.7	2.9	3.1	4.1	4.7	5.4	6.9

The data given in Table IV make it plain that it is much cheaper to use a fan or blower for moving air than to employ a tall chimney, and that the practice of heating the air in foul-air flues or ventilating stacks, in order to create additional draft, is very expensive and wasteful.

MOVEMENT OF AIR IN FLUES

45. Fundamental Principles.—It is commonly said that ventilating chimneys, or vertical vent flues, have a *suction*, and that they *draw* air into them from the rooms with which they are connected. These statements are erroneous. Air, and all other fluids, move only when the pressure that impels them is greater than the pressure that opposes their movement. Hence, they are always *pushed*, and are never pulled or drawn.

In order to understand clearly the reason why hot air moves up a ventilating chimney, or flows from a flue into a room, it is necessary to examine carefully the condition of affairs throughout the entire extent of the chimney or flue.

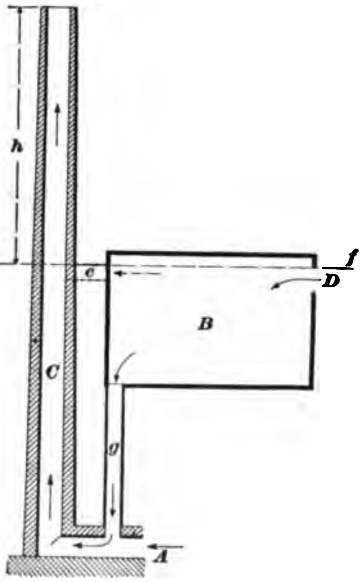


FIG. 7

For illustration, suppose that the flue shown in section in Fig. 7 is 120 feet high, that the temperature of the hot air in the flue is about 450°, the atmosphere being at 60°, and that the flue is closed at the top. The column of air inside the flue weighs less per cubic foot than the air outside, because it is greatly expanded by the heat. From Table I, the weight of 1 cubic foot of air at 60° is .0764 pound; hence, by the rule in Art. 5, the weight at 450° is $\frac{.0764 \times (460 + 60)}{460 + 450} = .04366$ pound. The difference is .0764 − .04366 = .03274 pound. The actual difference in the weight of two columns, one of external and the other of internal air, each 1 foot square and 120 feet high, will be

.03274 × 120 = 3.93 pounds. Consequently, the weight of the internal air cannot balance that of the external air; therefore, it will be driven upwards against the cover at the top with a force amounting to 3.93 pounds per square foot, or about .027 pound per square inch. There will then be a higher pressure at the top of the flue than at the base. The pressure at the bottom will be equal to that of the external atmosphere, or about 14.7 pounds per square inch, and it will increase gradually upwards, until at the top it will be 14.7 + .027 = 14.727 pounds per square inch.

The condition of the air in the interior of the flue is now precisely similar to that in an ordinary hot-air flue when all the registers are closed. The pressure of the hot air exceeds that of the atmosphere at each register, in proportion to its elevation above the furnace, radiator, or other heating surface. When a register is opened, the hot air flows into the room, because the pressure back of it exceeds the pressure of the air in the room. Now, if the top of the flue is opened to the atmosphere, the whole column of hot air in it will be driven rapidly upwards. But, as soon as the current begins to flow, the internal pressure falls, and when the current attains its full speed the internal pressure at the top will fall to about that of the atmosphere. The weight of the column of hot air, however, remains the same (the temperature being maintained constant); consequently, the difference in pressure at the top and bottom will be the same as before, that is, .027 pound per square inch. The pressure of the hot air at the bottom of the chimney will, therefore, be about .027 pound per square inch below that of the external atmosphere.

The excess of the atmospheric pressure above the interior pressure at the base of the flue or chimney is called the **draft**, and is usually measured in *inches of water*, whereby is meant the height of a column of water, in inches, whose pressure per unit of area at its base is equal to the draft pressure.

46. The tendency of all fluids is to flow toward an area of low pressure. The surrounding atmosphere cannot flow

down a chimney or flue, because the internal pressure of the hot air at the top equals or exceeds the atmospheric pressure, but it can and does flow in through the grate and combustion chamber or over the radiating surface into the area of low pressure within.

The velocity of the entering air will increase until the resistance that it encounters in passing over the radiating surface or through the burning fuel, added to that due to the friction of the flues, exactly equals the draft pressure.

As soon as the air reaches the radiating surface at the base of the flue or the fire, in the case of a boiler chimney, it is greatly expanded by the heat. As the heat is given off to the walls of the flue or chimney, the volume gradually diminishes until the air is discharged from the top of the flue or chimney.

47. The theoretical velocity of the current in the flue is equal to that acquired by a weight in falling through a distance equal to the difference between the height of a column of air at atmospheric temperature, having the same height as the flue, and the height of the same column when expanded by the heat to the actual temperature of the air or gases in the flue.

The height of the column will increase directly with the increase of absolute temperature. The velocity acquired by a falling body is in all cases very nearly 8.02 times the square root of the distance fallen through.

To find the theoretical velocity, in feet per second, of the gases in a chimney, or ventilating flue, proceed by the following rule:

Rule.—*Multiply the height of the flue, in feet, by the difference in temperature of the gases and of the atmosphere, in degrees, and divide by the absolute temperature of the atmosphere. Extract the square root of the quotient, and multiply it by 8.02. The result will be the theoretical velocity sought.*

Or,
$$v = 8.02\sqrt{\frac{H(t_1 - t)}{T}}$$

where t = temperature of atmosphere;
t_1 = temperature of chimney gases;
T = absolute temperature of atmosphere;
H = height of chimney, in feet;
v = velocity, in feet per second.

EXAMPLE 1.—What is the theoretical velocity of the current in a chimney 120 feet high, the temperature of the gases being 450° and that of the atmosphere 60°?

SOLUTION.—Applying the rule,

$$v = 8.02\sqrt{\frac{120 \times (450 - 60)}{460 + 60}} = 76.08 \text{ ft. per sec. Ans.}$$

EXAMPLE 2.—What will be the theoretical velocity of warm air having an average temperature of 90° in a flue 25 feet high, the atmospheric temperature being 60°?

SOLUTION.—Applying the rule,

$$v = 8.02\sqrt{\frac{25 \times (90 - 60)}{460 + 60}} = 9.63 \text{ ft. per sec. Ans.}$$

48. The theoretical velocities computed by the rule in Art. **47** cannot be attained in practice, because of the friction and other resistances offered by the flues. The allowance that must be made for friction, etc. varies from 20 to 50 per cent. The hot air in chimneys attached to boilers and furnaces is mixed with a large percentage of carbon dioxide, which is much heavier than air. The weight of the hot air is thereby increased, the draft pressure is diminished, and the velocity of flow is correspondingly reduced.

The actual, or operative, height of a flue or chimney should be measured from the top of the stack to the inlet of the air, where it enters the furnace, or heating chamber. Only the actual difference in elevation should be considered; the horizontal distances that may be involved must be disregarded. Thus, in Fig. 7, the operative height of the ventilating chimney, when the hot air enters at A, is the total height of the stack C; but, when it enters at the level of the line ff, the operative height is only that part which is above the line, as indicated by the distance h. The stack will act as a siphon, and will draw the warm air downwards out of the room B through the flue g, provided that the opening at A is closed

and the fresh air is taken in at *D*. The operative height of the stack will then be equal to the distance *h*, and the draft will be about the same as though the connection to the stack were made as shown by the dotted lines at *e*. In practice, the draft will be better when the connection is made at *e* than when the current passes down the flue *g*, because the hot air will lose some of its heat in making the longer circuit, and there will also be more friction.

Chimneys and flues that are cold, or have never had a fire connected to them, will usually exhibit a considerable draft. This is due to the fact that the earth warms the air near its surface. Ordinarily, the air thus warmed rises only a short distance before it is cooled and dispersed by convection in the atmosphere, but that which passes up the ventilating stack is protected from convection, and is maintained in an unbroken stream to the top of the stack.

49. Frictional Resistance of Ducts and Flues. The resistance encountered by air in moving through ducts and flues is usually spoken of as *friction*, although the term, as thus used, is not strictly accurate.

The resistance arises from several causes: (1) Skin friction, which is the actual friction of the air against the surfaces over which it passes; (2) the abrupt changes of direction of the current at elbows and tees; (3) the movement of one part of the current on another, in passing around curves; (4) the abrupt changes in velocity that occur at pockets and enlargements; (5) the formation of whirls, or eddies; (6) the interference of currents.

50. The resistance due to skin friction varies: (1) Directly as the length of the pipe or flue; (2) inversely as the diameter, or, if square, as the length of a side; (3) directly as the square of the velocity. Hence, other things being equal, the pipe should be as short as possible; its diameter should be as large as possible; and the quantity passing through it in a given time should be as small as circumstances will permit. The last consideration is the most important of all, since if the quantity passing through a given pipe is doubled, the

velocity is also doubled, and the resistance is increased 2^2, or four times. The condition of the pipe itself, whether smooth or rough, also affects the force required to overcome the friction, a smooth pipe offering less resistance than a rough one. Hence, metal pipes are to be preferred, in this respect, to brick ducts. A polished pipe offers less resistance than a smooth one not polished. A pipe or flue having its inside covered with a deposit of dust or dirt offers much greater resistance than a similar pipe that is clean.

51. When a current of air encounters an obstacle, as in Fig. 8, the particles composing the current are compelled to deflect from their normal direction and move sidewise sufficiently to pass by the obstruction. When a moving body is thus deflected from its course, it loses some of its kinetic energy. The energy thus lost will be expended on the dead air at *a*, and will compress it. The particles of air that have passed the edges of the obstruction tend to continue their

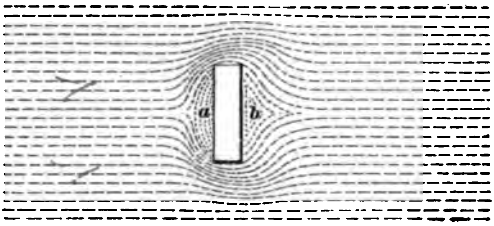


FIG. 8

forward motion in a straight line. If they actually did so, there would be a vacuum at *b*, but the pressure existing in the outer parts of the current compels them to flow together again behind the obstruction. Thus, *a* is an area of high pressure and *b* is an area of low pressure. The power expended in maintaining these two areas is taken from the current, and the motive force of the current is thereby reduced to that extent.

52. When a current is compelled to change its direction abruptly, the kinetic energy of the particles tends to move them as shown in Fig. 9. An area of high pressure will be

formed at *a*, and another of correspondingly low pressure at *b*. The effective area of the pipe or conduit will be reduced at *c*, and the velocity of the fluid will be greater at that point

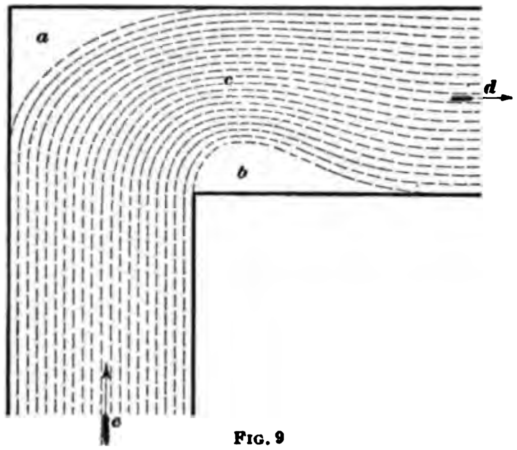


FIG. 9

than at *e* and *d*. Thus, the force that is spent in maintaining the abnormal pressures at *a* and *b*, and in imparting the increase of velocity at *c*, is all wasted.

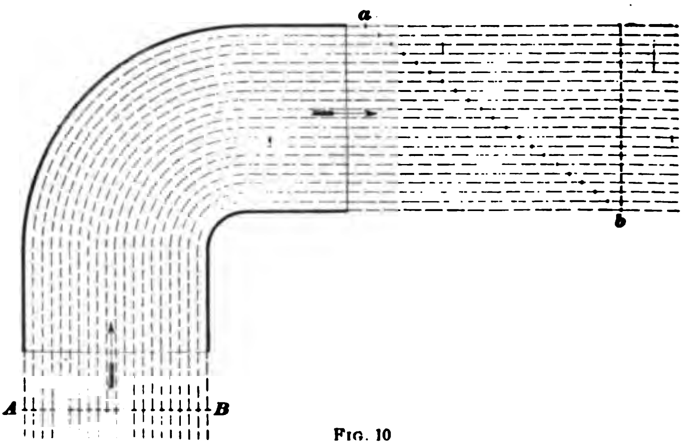


FIG. 10

53. If the turn is less abrupt than in Fig. 9, as in Fig. 10, the waste of energy is considerably reduced. The tendency

to form high- and low-pressure areas, as in Fig. 9, is nearly destroyed, but the particles of the air are still compelled to slide over each other. Thus, the particles at *A* and *B* will reach the points *a* and *b*, respectively, at the same time, if they travel equal distances in equal times. The power expended in sliding the particles of air on each other is wasted. This loss cannot be avoided, whether the turn is made sharply, as in Fig. 9, with a small radius, as in Fig. 10, or with a large radius, as in Fig. 11. But, the time afforded

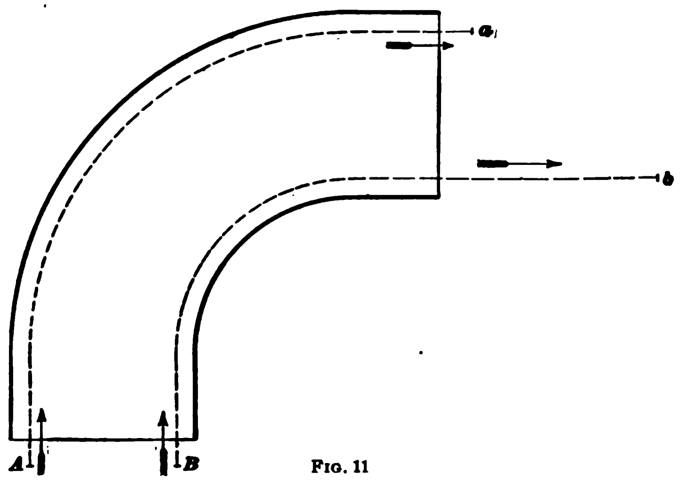


FIG. 11

for making the change of direction (the velocity being the same in each case) is much greater in Fig. 11 than either of the others. The force required to deflect a moving body from its normal path is inversely proportional to the square of the time in which the change of direction is made. Hence, if the change of direction is made in 2 seconds in Fig. 10, and in 4 seconds in Fig. 11, then $\frac{4^2}{2^2} = 4$ times as much force will be required when turning the curve of shorter radius.

54. The effects of pockets or enlargements in a pipe are shown in Fig. 12. The particles *E*, *E* near the surface are compelled to change their direction twice while passing the enlargement. They flow outwards into the corners *a*, *a*, and

inwards out of the corners *b*, *b*; while the particles in the center, as at *H*, pass through without interruption. Hence, the outer particles are retarded, and the central particles *H* are compelled to slide forwards on them.

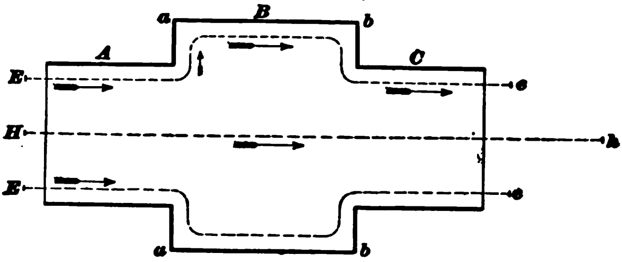


FIG. 12

When the air particles pass out of the part *A* into the enlargement *B*, they are obliged to fill a space of larger diameter. To do this, their velocity must be checked; and when they enter the part *C*, their velocity must be restored and made equal to that in part *A*. To thus alternately check and accelerate the velocity requires the expenditure of energy; the energy thus spent is wasted.

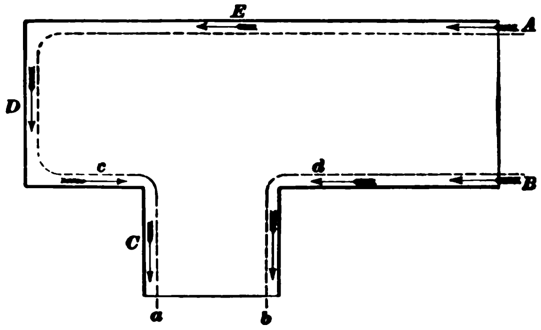


FIG. 13

55. The effect of a dead end in a pipe duct is shown at *D* in Fig. 13. The particles entering at *A* travel around the dotted line *ED* to *a*, and thus move through a much longer distance than the particles that enter at *B* and travel around to *b*. At the points *c* and *d*, the currents oppose each

other and thus waste energy. The dead end of the pipe will be filled with an eddying, whirling mass of air. The energy expended in maintaining these eddies is wasted.

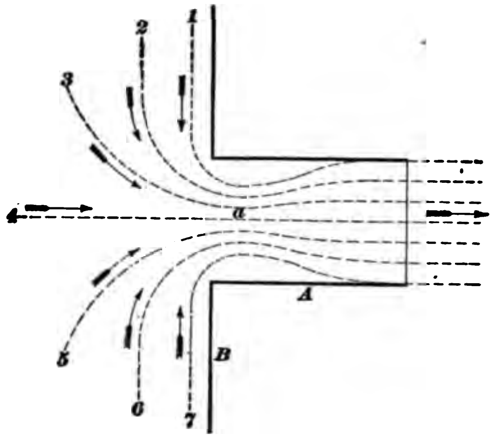


FIG. 14

56. The effect of opposing currents is shown in Fig. 14, which illustrates the formation of what is called the **contracted vein.** The branch *A* is attached at right angles to a chamber or reservoir *B*. It will be seen that the particles that move on the lines *1* and *7* would collide if their motion were continued, and would destroy each other's motion. Their energy is expended, however, in deflecting the other parts of the current somewhat out of their course. The effect of the opposition of the various currents is to reduce the diameter of the stream at *a* to less than the diameter of the branch *A*. Consequently, the amount of air that will be delivered through the branch will be less than it should be. The trouble may be remedied by providing the branch with a mouthpiece, curved so as to properly guide the parts of the current

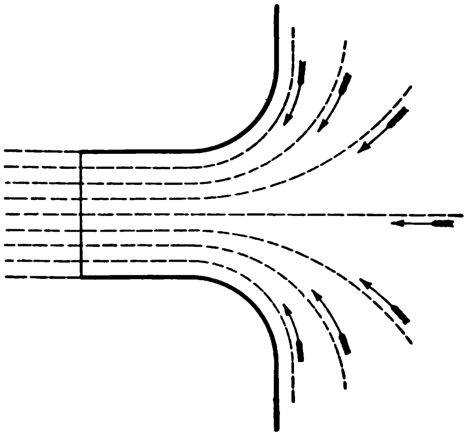


FIG. 15

as shown in Fig. 15. The branch will then discharge to its full capacity.

57. The resistance to the flow of air through pipes or ducts is represented by the formula

$$R = \frac{f d s v^2}{2g}$$

where R = resistance;
f = coefficient of friction;
d = density of air;
s = surface in contact;
v = the velocity, in feet per second;
g = acceleration due to gravity, which is equal to 32.16 feet per second.

It is unnecessary, as a rule, to compute the resistance in heating and ventilating work; the above equation is given merely to show the factors that determine the resistance, which is proportional to the surface in contact and to the square of the velocity. The other factors in the equation vary through relatively narrow limits.

The surface in round pipes per square inch of cross-sectional area decreases with increase in the size of the pipes; for example, a 5-inch pipe has .8 square inch of surface per inch in length for each square inch of area; a 10-inch pipe has only .4 square inch, or half as much. In other words, the resistance to the flow of air varies inversely as the diameter of pipes. The surface and the resistance are directly proportional to the length. With rectangular pipes, the nearer they are to being square in shape the less will be the resistance to the passage of air. The fact that the resistance varies as the square of the velocity shows the lack of economy in high velocities. There is a limit to low velocities, on the other hand, below which it is not wise to go on account of the lack of control of the distribution.

MEASUREMENT OF AIR MOVEMENT

58. Measurement of Air Volume.—In order to estimate the efficiency of a ventilating plant, it is necessary to take measurements of the air-currents and correctly compute

the volume of air moved in a given time. To do this, two things must be known. First, the sectional area of the flues, or ducts, through which the air flows, and, second, the velocity with which the air moves in each duct. From this data, the total quantity of air passing through the rooms of the building in any given time may be computed by simply multiplying the sectional area of the duct in square feet by the velocity in lineal feet per minute and by the time in minutes.

If the velocity is the same in all of the air ducts, the sum of the sectional areas of the ducts multiplied by the velocity will give the total volume delivered; but the velocities vary considerably in different-sized ducts, even though the motive force is the same for all, and hence it is usually necessary to find separately the volume delivered by each duct.

In estimating the quantity of air flowing through the building in 1 minute, particular care must be taken to measure the air only as it enters the rooms, or only as it leaves them; otherwise, the same air will be measured twice, and the estimate will be wrong.

It is usually most accurate to measure the inlet currents, when the building is ventilated mechanically, by what is known as the plenum fan system (that is, when the air pressure in the building is greater than that of the external atmosphere) or by the natural-draft or gravity system; and to measure the outlet currents, that is, the currents in the vent flues, when the building is ventilated by the exhaust system (that is, by fans or some other motive power operating in the vent flues, which lowers the pressure of the air in the building below that of the atmosphere).

59. Many different instruments are used for measuring the velocity of air-currents and there are many ways of applying them; they may generally be classed, however, as *anemometers*, and *pressure gauges*, or *manometers*. The anemometers indicate velocity only; the manometers indicate pressures only.

Anemometers are sometimes classed as *static* and *dynamic*, the former being those that indicate the velocity by a change

in position of a disk or other body suspended or otherwise set in the air-current; the latter are so constructed that the velocity of the air-current can be determined by the rate at which it causes a propeller-like wheel, placed in its course, to revolve.

60. Fig. 16 shows a simple **static anemometer** applied to the face of an ordinary wall register. It is composed of a paper disk, or fan, *a*, hinged loosely to a cork *b* in such a manner that it may swing easily to or from the face of the register *c*. A light stem, say a broom straw *d*, connects *a* to *b*. A quadrant *e* that is divided into a scale representing the velocity, in feet per second, is attached to the cork, and the stem *d*, by moving over its face, acts as a pointer. If there is no air passing out of the register, the force of gravity will cause *a* and *d* to hang in a vertical position; but when a current flows from the register face into the room, it will blow the disk *a* forwards and *d* will be inclined as shown in the figure, at an angle that will vary with the velocity.

FIG. 16

61. In ventilation, the only use for static anemometers is to apply them as permanent fixtures in air-currents, so that they may constantly indicate approximate velocities or velocity variations. These instruments cannot be used for accurate determinations of mean velocities, because they indicate the velocity of the air at the point of their application

only. The velocity of a given part of an air-current is not necessarily the same as that of some other part of the current. For instance, the velocity at the center of an air-current is usually higher than that near the sides, which, of course, is due to the fact that the air particles near the sides are retarded by skin friction, that is to say, they do not travel as fast as those in the middle of the current, because they are held back by rubbing against the inner surface of the pipe or duct that serves to conduct the air-current.

If, then, the anemometer is placed in the center of the air-current, the velocity indicated will not be the velocity by which to accurately determine the volume of air delivered by the duct; the velocity thus obtained will be too high, and, if multiplied by the sectional area of the duct, the product, that is, the quantity of air delivered, will be correspondingly far from the quantity actually delivered.

If, on the other hand, the instrument indicates the velocity close to the sides only, and this velocity is multiplied by the sectional area of the duct, the quantity of air thus obtained will be much less than the actual quantity delivered.

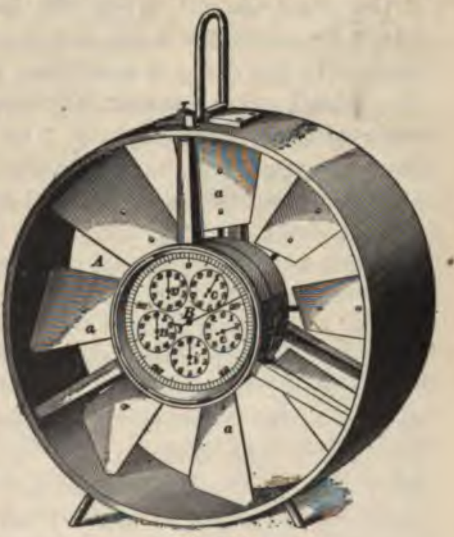


FIG. 17

62. To determine the actual quantity of air delivered, the *mean velocity* of the air-current, that is, the average velocity, must first be found; this can best be obtained by the use of the **dynamic anemometer,** a good form of which is illustrated in Fig. 17. It consists of a wind wheel *A* and a registering device *B*. The wind wheel is composed of a light spider having eight

arms to which are fastened very light blades, or vanes, *a*, *a*. The arms of the spider are so twisted that the blades, or vanes, make an angle of 45° with the plane of the wheel, so that when the anemometer is placed in the path of an air-current, it causes the wind wheel to revolve. The motion of the wind wheel is communicated by its arbor to the registering device *B*. This device consists of a train of gears in the reducing order of units, hundreds, thousands, etc., so as to obtain the inverse readings of units, hundreds, thousands, etc. The arbor of the wind wheel and that of each gear of the train carry on their ends index pointers that show, on separate dials, units, hundreds, thousands, etc., as illustrated in Fig. 17. Suppose that each index pointer is at the *0* mark of its dial. When the wind wheel has made 100 revolutions, the large pointer in the center of the dial has made one revolution, or it has moved from *0* to *0* on the large dial. Therefore, each space of the dial represents one revolution of the wind wheel. While the large pointer moved from *0* to *0*, or while the wind wheel made 100 revolutions, the pointer on the dial *c* moved from *0* to *1*, as shown. If the wind wheel makes another 100 revolutions, this pointer will move another space, or from *1* to *2*. It will move one of these spaces for each 100 revolutions of the wind wheel. Therefore, the pointer of this dial indicates hundreds of feet, and the large dial anything less than a hundred feet. If, now, the wind wheel should make so many revolutions as to cause the pointer of the dial *c* to make one complete revolution, or to cause it to move from *0* to *0*, the pointer of the dial *c* would move from *0* to *1*; therefore, the pointer of this dial indicates thousands of feet. That this is true will be clear from the following: In order to move the pointer on the dial *c* one division, the wind wheel had to make 100 revolutions, and since the pointer of the dial *c* had to move ten divisions to make 1 revolution, the wind wheel must make $10 \times 100 = 1{,}000$ revolutions.

In the same manner, it may be calculated and shown that the pointers of the dials *i*, *n*, and *v* indicate ten thousands, hundred thousands, and millions of feet, respectively.

63. Anemometers like that illustrated by Fig. 17 are usually so constructed that when the air that passes through the wind wheel moves 1 foot horizontally, the wind wheel will make 1 revolution; therefore, if the large pointer were at *0* of the large dial, and the instrument were placed in a current of air for 1 minute, and after removing it the pointer was at the *76* point of the dial, then the velocity of the current would be 76 feet per minute. Suppose all the pointers to be at their *0* marks, and the instrument placed in a current for 1 minute. If, on looking at the pointers, it is found that the pointer of the dial *e* is at *2*, that of the dial *c* at *1* and that of the large dial at *18*, as shown in the figure, what is the velocity of the current?

Since the dial *e* records thousands of feet, write down 2,000; since the dial *c* records hundreds of feet, write down 100, and since the large dial records 18 feet, write down 18. Therefore, the sum of these, or 2,118 feet, is the velocity of this current per minute.

64. To make the readings more accurate, anemometers are supplied with an attachment for disconnecting the registering device while the wind wheel is in motion, without stopping the wind wheel. Such an attachment is shown at *r*, Fig. 17. By moving *r* to the right, the registering device is in gear, and the pointers will move when the wind wheel revolves; and when *r* is moved to the left, the wind wheel may still revolve, but the pointers will not move.

65. A good idea of the operation of action of this instrument may be obtained by the following example: The first thing to do is to read the instrument and note the number registered on it, since it is impossible to have the instrument at zero on all the dials at all times. Suppose that the instrument is standing at 15,472, and after it has been held 3 minutes in the current, the reading is 17,740. Now, the last reading is greater than that at which the instrument stood before it was put in the current by 17,740 – 15,472 = 2,268. In other words, the wind wheel made 2,268 revolutions in 3 minutes, and therefore in 1 minute it made

$\frac{2,268}{3} = 756$ revolutions. The velocity of the air-current is, then, 756 feet per minute.

Further, notice that 17,740 will be the first reading the next time the instrument is used.

When the anemometer is first held in a current, it loses from 30 to 50 revolutions before the inertia due to the moving parts is overcome. The result is that to all readings a certain constant must be added. The constant is supplied by the maker of the instrument. If 30 were the constant for the case mentioned, the correct reading would have been $\frac{2,268 + 30}{3} = 766$ revolutions per minute, corresponding to a velocity of 766 feet per minute.

66. In applying the anemometer to currents of air flowing through registers, etc. into a room, the natural conditions should be allowed to exist, that is to say, the register should not be removed from the face of the air duct; because, by doing so, the velocity of the air-current will be increased on account of the free opening, and a much larger volume of air will enter the room than really enters when the register is in place. The grating forms a resistance to the flow, and, consequently, reduces the volume delivered.

FIG. 18

It is quite a difficult matter to obtain even a fairly close approximation to the volume of air flowing through registers, because the sectional area of the current must be known as well as the velocity, and this cannot be determined over the face of a register, since the air comes through the numerous small openings with a high velocity and mixes directly with

the air in the room. Approximate readings are often taken by moving the anemometer to and fro over the face of a floor register, on a horizontal plane about 1 or 2 inches above it.

Probably the best method, however, is to make a sheet-iron tube *a* (see Fig. 18) that will enclose the perforations in the register grating, as shown. The tube will envelop the air-current and cause it to flow through in a body, the sectional area of which can easily be measured. The anemometer is held over the orifice of the tube, as shown, and is steadily moved back and forth, and a very close approximation to the mean velocity is thus obtained.

67. It is not a simple method to ascertain the quantity of air entering a room through a wall register or other grating, because of the inevitable eddies formed by a sharp bend or elbow. For example, Fig. 19 shows a vertical flue *a*, with a rectangular grating *b* over its orifice. The air flows in the direction of the arrows, and eddies that very much affect the outflow of air from the lower part of *b* are formed at *e*. If the anemometer is applied at the face of *b*, a very inexact reading will be obtained, even though a short tube is used to envelop the current.

Fig. 19

Probably the best and most simple method of computing the quantity of air delivered from such a flue is to take off the grating, insert the anemometer *c* (which is attached to a wire handle) in the flue, as shown, and work it back and forth, after the grating has been replaced. By this method, a very

accurate determination of the velocity of the current in the flue can be obtained, and the sectional area of the current at the part where the anemometer was applied can easily be found.

When taking measurements of the velocity of air, particular care must be taken to stand clear of the current, so as not to obstruct it in any way; otherwise, the computations will be more or less inaccurate.

68. In measuring and computing the volume of air, the temperature at the time of measurement must always be taken into account. For convenience in comparing one measurement with another, the volumes should all be reduced to corresponding volumes at 460° absolute, which may easily be done by the rule in Art. **4.** In measuring the volume of air that passes through any pipe, care should be taken that the measurements of velocity, area of the flue, and the temperature of the air be all made at the same place.

69. The velocity of air under pressure in pipes may be measured by means of **Pitot's tube**, which is shown in Fig. 20. It consists of two tubes *a*, *b* inserted in a suitable plug *c*. The lower end of *a* is square, but that of *b* is curved to face the current, as shown. The upper ends of the tubes are connected to a water gauge *d*.

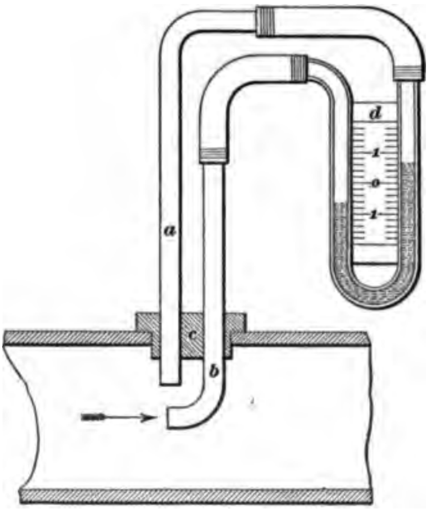


FIG. 20

The pressure that affects the gauge is due to the momentum of the air that strikes the open end of the tube *b*. The velocity corresponding to any particular indication of the attached water gauge may be found by means of the tables furnished by the instrument maker.

70. Measurement of Air Pressure.—The pressure of air, as commonly used in heating and ventilation work, is very small; it may be measured by means of the **water gauge.** This is constructed in many forms, the simplest of which is shown in Fig. 21. It consists of a glass tube with two arms *a*, *b* partly filled with water. The upper end of the tube *a* is open to the atmosphere, and the end of the tube *b* is inserted in a cork *c*. When the pressure in *a* exceeds the pressure in *b*, the water will sink in *a* and rise in *b*, as shown. The difference in the levels of the water in the tubes, measured in inches, indicates the difference in pressure, in inches of water.

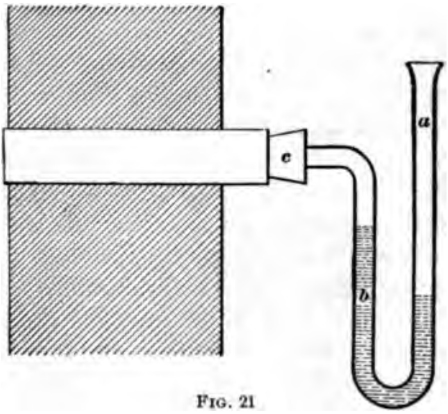


FIG. 21

To measure the draft pressure in a chimney or flue, a connection should be made to the interior by means of a piece of ¾-inch iron pipe, which should be cemented air-tight in a hole through the brickwork. The water gauge may then be inserted in the cork *c*, and the cork pressed firmly into the end of the iron pipe, as shown, taking care that the gauge arms stand vertically. The difference in level can then be measured by means of a common rule held behind the tubes.

71. The water gauge shown in Fig. 21 is not sufficiently sensitive or delicate for the accurate measurement of very light pressures, and special modifications are made for that purpose, as shown in Figs. 22 and 23.

The **differential air gauge** is shown in Fig. 22. The tubes *a*, *b* are connected to large bulbs, or chambers, *c*, *d*. The bulbs of the instrument are filled with two liquids that have a small difference in weight. Under equal pressures, the lighter liquid in *c* will stand at a slightly higher level than

that in *d*. When pressure is applied to *d*, for example, the dense liquid will rise in *a* until the difference in weight of the two columns, measured from the surface of the liquids in the bulbs, balances the extra pressure. The sensitiveness of the instrument will depend on the smallness of the difference in the weight of the liquids employed. If pressure is applied to *c*, the movement of the column will be downwards, and if the oil or other light liquid should be driven past the bend at the bottom of the tubes, it will rise through the denser liquid in the tube *b*, and will impair the working of the instrument.

When this instrument is used as a draft gauge, the connection to the chimney or ventilating flue is made through the bulb *c*.

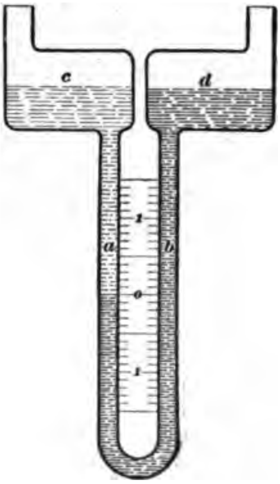


FIG. 22

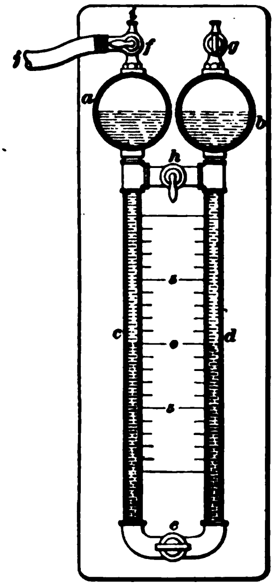


FIG. 23

72. Hoadley's differential draft gauge is shown in Fig. 23. Its main features are two equal chambers *a*, *b* connected by means of tubes *c*, *d* and cocks *e*, *h*. The instrument is connected to the chimney or flue by means of the rubber tube *j* and an iron pipe similar to that shown in Fig. 21. The three-way cock *f* serves to open or close communication from the chamber *a* to the flue or chimney, and also to admit

or shut out the atmosphere through the nozzle *i*. The atmosphere may be admitted to the tube *b* through the petcock *g*.

The lower parts of the tubes are filled with a mixture of water and alcohol up to the zero of the scale. The upper part of the instrument is then filled with a liquid that is lighter than water, usually olive oil. Care is taken to have the surfaces of the oil in the chambers *a*, *b* at exactly the same level, and to have the water stand at equal heights in the tubes *c*, *d*. To use the instrument, the cock *h* is closed, *g* and *e* are opened, and *f* is opened to the chimney or flue through the tube *j*. The water rises in *c*; *e* is then closed, and *f* is closed to the flue or chimney and opened to the atmosphere. The surface of the oil now stands higher in *a* than in *b*. By opening *h*, the oil flows from one chamber to the other, and again comes to a level in both; *h* is then closed, *e* is opened, and connection is again made to the chimney. The water now rises higher in *c*. This operation is repeated until the water refuses to rise any higher in the tube *c*, and there is no difference of level in the contents of the chambers *a*, *b*. The difference in the height of the water columns is then read from the scale. The excess of pressure in the chamber *b* over that in *a* is equal to the difference in weight of the columns of the water and oil, having a height equal to the reading taken from the scale.

It will be seen that by using two liquids that have but a small difference in specific gravity, the instrument may be made to measure exceedingly light pressures.

VENTILATION

DEFINITION AND PURPOSE

73. Ventilation may properly be defined as the systematic and continuous removal of foul air from rooms used either for habitation or for manufacturing purposes, and the constant introduction of fresh air to take its place. To constitute a system of ventilation, these operations must be

practically continuous, at least during the time that the premises are occupied by persons or animals. The occasional airing of rooms by opening the doors and windows, allowing the fresh outdoor air to enter and dilute or displace the vitiated atmosphere, is called *aeration*, and is not considered as coming strictly within the meaning of the term ventilation.

74. Ventilating processes are used for many purposes other than the purification of the air in dwellings, etc. They are employed for removing smoke and offensive odors given off during manufacturing operations; to carry away the steam and vapor from drying rooms and dye houses; to expel and disperse poisonous or explosive gases, such as are found in coal-mining operations; to drive off overheated air and keep the temperature of rooms down to a proper degree; to prevent sunshine and the heat of the outer atmosphere from penetrating into ice houses or cold rooms, and to maintain a uniform degree of cold and dryness in cold-storage warehouses. Ventilating processes are also employed in stables and barns occupied by horses, and notably for the benefit of milch cows.

In studying the subject of ventilation, it is necessary to consider the physical properties of air and gases, and the variations in them caused by changes in the weather; the nature, source, and extent of the emanations that contaminate the air and make its removal necessary; the means that are available for moving it in the manner desired, and the apparatus best adapted for that purpose; and also the proper manner of arranging and constructing buildings so as to secure good ventilation at all seasons, and at reasonable cost. The air furnished to dwellings, etc. must be thoroughly adapted to the wants of the inmates at all times, being warmed in winter and cooled in summer. It should be regulated as to quantity and humidity, and its purity must be assured under all circumstances. The subject of ventilation, therefore, includes not only the movement and distribution of air, but also the heating, cooling,

drying, humidification, and purification that are necessary to fit it for use.

75. The primary object of ventilation is the removal of vitiated air. This being done, natural air, presumably of better quality, will flow in from all directions to take its place. The preparation of this fresh air for use by warming and otherwise is a secondary matter, although one of great importance.

The need of heat for warming purposes is universally understood, but the necessity of having pure air to breathe is not so well known—indeed, many people, otherwise well informed, regard the demand for pure air as an unnecessary refinement. It may be noted, however, that people can endure great variations in the temperature without injury, merely by adjusting the amount of their clothing, but that they cannot breathe foul air without paying the full penalty in every case, and that there is no possible way of adjusting the human organism so as to be unharmed by it.

While all diseases are aggravated by inhaling bad air, it is not known with certainty that any specific disease is directly traceable to its influence. Of course, if the air is infested with disease germs thrown off from persons suffering from smallpox, typhus, cholera, consumption, or other contagious diseases, the breathing of air contaminated by such impurities will operate to spread these malignant affections by conveying the germs into the mouth and lungs of healthy people.

The evil effects of the habitual breathing of vitiated air, by both men and animals, have been carefully observed for long periods of time. The most noticeable and certain effect is the lowering of the vital energies of persons thus exposed, producing what is called *general debility*, and making them very susceptible to disease in all forms. Healthy people possess a high resisting power against disease, but the continued inhalation of impure air constantly diminishes this power of resistance, until the persons thus affected easily succumb to any adverse influence that may be brought to

bear on them. Children have less vital energy than adults, and are more quickly and seriously affected.

76. Good ventilation is not only desirable for the pleasure afforded by breathing fresh, invigorating air, but is also absolutely necessary for the maintenance of good health, and to prevent the spread of infectious diseases. It is highly desirable, also, as a matter of cleanliness. No civilized person will consent to take into his mouth any article of food that has been in the mouth of another, or to put on under-clothing that has been worn by some other person. There is precisely the same reason for refusing to inhale the air that has been ejected from the lungs of other people, or to breathe air mingled with the vapor and odors given off from their bodies and clothing.

It cannot be said that good ventilation has been attained until each person is supplied with air in proper quantity, of proper temperature, without drafts, and free from all animal exhalations, street dust, gases of decomposition, or products of combustion.

GENERAL REQUIREMENTS

77. The requirements for the successful ventilation of the various classes of buildings that are occupied by human beings are alike in principle in all cases. The ventilating engineer should bear in mind that ventilation is a sanitary necessity, and should realize that the physical health of those who occupy the premises to be ventilated depends in a large degree on the skill and faithfulness with which he plans and executes his work. His patrons have in most cases very hazy and often mistaken ideas of what is necessary and proper, and consequently are unwilling to expend sufficient money to secure proper ventilation. He has, therefore, to protect these people against their own ignorance and parsimony.

Considering the matter from a sanitary standpoint, the problem of ventilating the ordinary dwelling, containing from four to eight rooms, must be regarded as the most important, because the vast majority of people are housed

in that kind of building, and are vitally affected by the conditions prevailing in them. Schoolhouses come next in importance, being occupied by large numbers of children for from 4 to 6 hours per day. Children are much more susceptible than adults to unsanitary influences, and must therefore be guarded with the utmost care. Next in importance are the manufactories, containing large numbers of people engaged in labor for from 8 to 12 hours per day. Public buildings, such as theaters, churches, audience rooms, and legislative halls, although they receive the greatest share of public attention, are really of less importance to the sanitarian, because they contain comparatively a smaller portion of the population, and are occupied only for short periods of time.

QUANTITY AND QUALITY OF AIR REQUIRED

78. In order to answer properly the question: What should be the quantity and quality of the air supplied for purposes of ventilation? it is necessary to consider the effects produced by breathing foul air, not merely for a few hours, but for long periods of time. A large number of competent investigators have observed its effects on soldiers occupying poorly ventilated barracks, and on operatives working in closed workrooms, etc., the observations extending over a period of many years. A comparison of the results thus obtained proves the slow but certain production of throat and lung troubles, and a constant loss of energy and vitality that shortens life to a serious extent, and makes existence a burden instead of a pleasure.

There is only one way by which the fitness of air for respiration can be determined with any certainty, and that is by chemical examination. The sense of smell cannot be depended on for this purpose, because it is so easily blunted. After remaining for 10 or 15 minutes in a room full of bad air, a person will usually be unable to perceive any unpleasant odor about it. It is only on passing from the fresh outdoor air into a tainted atmosphere that the sense of smell can be relied on to discover the bad quality of the air,

but even then no accurate estimate can be made of the real degree of pollution.

79. Two parts of carbon dioxide per 10,000 parts of air in excess of that already contained in the atmosphere, which is about 4 parts, is claimed by scientists to be the point of maximum vitiation permissible in air of standard respirable purity. In order to properly ventilate a room, that is, to prevent the vitiation of the air within it from exceeding this standard of purity, a quantity of fresh air must enter the room, be diffused with the vitiated air, and, by passing again to the outer atmosphere, carry a quantity of the foul matter with it. In order to find the quantity of fresh air required, it is first necessary to ascertain the capacity of the vitiating agents to contaminate the air. For instance, adult males each evolve about .7 cubic foot of carbon dioxide per hour; adult females, .6; children, 3.5 to .5; candles, .3; oil lamps about 1.2; common gas burners about 1.2. The amount of air required per hour to keep the vitiation down to the limit proposed may be found as follows:

Rule.—*Multiply 10,000 by the cubic feet of carbon dioxide evolved per hour, and divide the product by the excess number of parts of carbon dioxide allowed per 10,000 parts of the fresh air. The quotient will be the cubic feet of fresh air required per hour.*

Or,
$$Q = \frac{10{,}000\,a}{b}$$

where Q = fresh air per hour, in cubic feet;
a = carbon dioxide evolved per hour, in cubic feet;
b = difference in the number of parts of carbon dioxide per 10,000 parts in the vitiated air and fresh air.

EXAMPLE.—A room containing 50 men and 40 women is lighted by 48 gas jets. How much fresh air is required, per hour, in order that the quantity of carbon dioxide may not rise higher than 2 parts in 10,000 parts above that already contained in the fresh air?

SOLUTION.—Applying the rule,

$$Q = \frac{10{,}000 \times (50 \times .7 + 40 \times .6 + 48 \times 1.2)}{2} = 583{,}000 \text{ cu. ft. per hr.}$$

Ans.

80. When a definite animal or musty odor begins to be perceptible, the air is said to be *rather close*, and the exhaled carbon dioxide is found to amount to 4 or 5 parts per 10,000 in excess of that normally present in the atmosphere. When the proportion increases to 7 or 8 parts in excess, the air is called *very close*, and when it reaches 12 parts in excess, the air is pronounced *very bad*. Beyond this point, the sense of smell fails to perceive any marked difference. Proper ventilation requires that the exhaled carbon dioxide should not be allowed at any time to rise above 2 parts per 10,000 in excess of the amount normally present in the atmosphere. Not only does each adult person in good health exhale, while at rest, about .7 cubic foot of carbon dioxide per hour, but in the same time there is exhaled from the lungs and skin about .091 pound of water that at 70° becomes about 80 cubic feet of steam or vapor. Each person also imparts about 400 British thermal units per hour to the air of the room, by conduction and radiation from the body. The air supplied for ventilation must, therefore, serve three purposes: to dilute the carbon dioxide to a proper degree; to absorb the vapors exhaled, without permitting any noticeable increase in the humidity; and to absorb the heat as rapidly as emitted, without perceptible rise of temperature.

In order to dilute .7 cubic foot of carbon dioxide to the proportion of 2 parts in 10,000, it is necessary to mix it with $\frac{10{,}000 \times .7}{2} = 3{,}500$ cubic feet of air. Therefore, the air supply should be 3,500 cubic feet per hour for each adult person.

Taking into consideration the smaller amount of carbon dioxide produced by children, the supply of air for schoolrooms and similar places may be taken at from 1,500 to 2,500 cubic feet per person per hour, the *Massachusetts standard* being 1,800 cubic feet. Inasmuch as it is difficult to secure perfect diffusion of the fresh air introduced for the purpose of diluting the impurities, so as to maintain the atmosphere in schoolrooms at the accepted standard of respirable purity, the air supply for schoolrooms should never be less than

1,800 cubic feet per pupil per hour. Ordinarily, this amount of air is also sufficient to absorb the vapor and bodily heat. The addition of 80 cubic feet of vapor to 1,800 cubic feet of air at 70° will not increase the humidity enough to be objectionable unless the moisture of the air is much too high on entering. The bodily, or animal, heat, however, has a more noticeable effect. As each British thermal unit will raise the temperature of about 55 cubic feet of air 1°, it follows that 400 British thermal units will heat 1,800 cubic feet about 12°. No such rise of temperature will be observed, however, except under extraordinary conditions, because a much greater amount of heat is lost from the room in the same time by conduction through the walls, windows, etc.

An allowance of 1,800 cubic feet per hour, or 30 cubic feet per minute, is the smallest that should ever be made, except in the case of small children, when 1,500 cubic feet per hour should be the minimum, and it is advisable to increase the supply whenever it can be done without unreasonable expense.

81. Thus far, in determining the quantity of air required, no account has been taken of any other source of contamination than the respiration and bodily exhalations of persons occupying the apartments. Lamps and gas burners produce large amounts of carbon dioxide, and occasionally other gases of a more harmful nature. Ordinarily, these products of combustion do not need so much dilution as the products of respiration, and for purposes of computation the allowable proportion may be assumed as 10 parts in 10,000. Electric incandescent lamps do not vitiate the air, because there is no combustion present. It must not be forgotten that when gas is burned, a considerable amount of moisture is added to the air, all of the hydrogen being converted into water. When a large number of gaslights is employed, the humidity is likely to be increased to an uncomfortable degree.

82. The volume of the air supply required varies with the season and the condition of the outer atmosphere. In clear, cold weather, 1,800 cubic feet per hour per head is

sufficient for good ventilation; on a mild spring day, with a damp, muggy atmosphere, it is difficult to get enough air without getting too much heat at the same time. The air is not dried in the least by passing through heaters, and on such days it is liable to be so moist and warm that the air passing out through the vent flues fails to remove the animal heat as fast as is necessary to insure comfort. Where people assemble in considerable numbers, as in schools, etc., moisture-laden air is liable to produce a feeling of lassitude, and even fainting spells. On such occasions, it is highly desirable to have some means for reducing the humidity of the air.

83. Generally speaking, it is impracticable to make calculations for ventilation or heating on a basis of the cubical contents of an apartment. The amount of air required depends solely on the number of persons occupying the room, and on the nature and extent of the air-contaminating influences. The size of the room does not necessarily enter into the calculation. Thus, 60 people require precisely the same amount of air whether they are packed in a railroad car or are scattered over a large hall. The requirements of heating are equally independent of the cubical contents or space. The amount of heat to be supplied depends wholly on the amount lost through cooling surfaces and by ventilation. It varies with every change in the temperature of the outer atmosphere, and must be modified to suit occasions of excessive humidity.

Thus it is seen that a knowledge of the dimensions of the space to be ventilated or warmed affords no data for computing the supply of either air or heat. All rules, therefore, that are based on the volume of the room are empirical, and are mere aids to guesswork. It is the practice of many heating engineers to assume that the air should be changed a certain (arbitrary) number of times per hour, instead of computing the amount required by the persons occupying the room. This proceeding, however, is not a rational one, and the results arrived at are little more than mere guesswork.

84. Cubic space is not a very important factor in ventilation, but a certain minimum space is required for each person, because the carbon dioxide and other exhalations from the body diffuse themselves through the air with comparative slowness, and in order to secure their dispersion into the atmosphere with proper rapidity, it is necessary that every person should have a certain amount of breathing room.

The minimum space that may be permitted, in cubic feet per person, is as follows:

	Cubic Feet
In a lodging or tenement house	300
In a schoolroom	250
Barracks	600
Ordinary hospital ward	1,000
Fever or surgical ward	1,400

85. Floor space must be considered as much as cubic space. Thus, in a schoolroom, there must be an aggregate of not less than 15 square feet of floor surface for each pupil; and in hospitals each bed should have 100 square feet of floor space. In stables, each horse or cow should have 100 square feet of floor space. A horse should have 1,600 cubic feet of air space, and a cow not less than 1,200. As cows are usually kept to furnish milk for food, it is important that they should be kept in a healthy condition, and that the air around them should be clean. The practice of furnishing their quarters with plenty of good air has been found highly beneficial.

PRINCIPLES OF VENTILATION

(PART 2)

VENTILATION OF BUILDINGS

DIFFUSION AND DISTRIBUTION OF AIR

DIFFUSION OF AIR AND OTHER GASES

1. When two or more gases are confined in the same enclosure or chamber, each gas will expand throughout the entire space. The pressure, or tension, of the mixture will depend on the proportion between its weight and the volume of the space within the chamber. Each gas will diffuse uniformly throughout the whole space; therefore, a mixture of gases will not separate into strata or layers by standing quietly for a long time, unless the gases are more than saturated. Stratification will begin when complete saturation is obtained. Some of the heavy gases diffuse slowly, and if the opportunity for diffusion is restricted, the body of gas may remain in the bottom of the enclosure for a long time. Thus, carbon dioxide may lie in the bottom of a covered pit or in a deep well, because the facilities for diffusion are too limited to insure a diffusion of the gas as fast as it is generated.

If two compound gases having a considerable difference in their capacity for heat are mixed and maintained under pressure, they will exhibit a strong tendency to separate in cooling. Thus, air and steam, when contained in pipes, will separate when the steam falls considerably in temperature. When the steam condenses, it is reduced to a small fraction

of its former volume, while the air with which it was mixed remains in the apparatus and occupies almost as much space as when it entered. The diffusion of steam in a mass of air that is confined in the same pipes and is under the same pressure as the steam is very slow.

2. The tendency of a gas, when released in still air, is to diffuse equally in all directions. The fact that it is heavier or lighter than an equal volume of air does not prevent or interfere with its complete and uniform diffusion. Gravitation does not affect diffusion to any appreciable extent. A mixture of light and heavy gases will always remain a perfect mixture, and will never separate into layers according to their weights, except under peculiar and artificial conditions that need not be considered here.

Carbon dioxide obeys the same law of diffusion as other gases; that is, it diffuses uniformly throughout space and does not ultimately settle down and form a heavy stratum at the bottom of a room. When carbon dioxide is found at the bottom, it is because it has not had sufficient time to diffuse properly. There is, however, a great difference in the rate at which various gases will diffuse. Hydrogen diffuses in air many times faster than carbon dioxide. The vapor, odors, and organic impurities exhaled from the body also require considerable time for proper dispersion.

Diffusion, strictly speaking, is merely a process of expansion. A quantity of gas liberated in a room has, when pure, an absolute pressure equal to that of the atmosphere; but, it expands until it fills the entire space uniformly, its absolute pressure falling in proportion. The diffusion of heavy gases may be hastened by convection or mechanical agitation, and it will be impeded by differences in temperature. Diffusion proceeds best when the whole body of air is at a uniform temperature.

In still cold air, the products of respiration, being warm, ascend at a rate slightly greater than the rate of diffusion; consequently, there is sometimes a little more carbon dioxide, etc. to be found near the ceiling than near the floor, but, as

a rule, it is uniformly distributed throughout the space. If there is a strong upward current of air from floor registers, gaslights, etc., the difference between the proportion of carbon dioxide at the ceiling and at the floor may be very great. It often happens in such cases that while the air at the breathing level is reasonably pure, at the ceiling it is fetid and suffocating. In order to secure good ventilation, this accumulation of bad air in the upper part of the room must be prevented.

3. The atmosphere of rooms may be changed in two ways: (1) by the diffusing, or mixing of the gaseous products of respiration with the purer air outside of the rooms; (2) by actual air-currents that serve to carry the foul air to the outer atmosphere. Ordinarily, ventilation is accomplished by combined diffusion and air-currents.

To grasp thoroughly the meaning of the word diffusion, and to understand clearly its relation to the ventilation of closed rooms, it may be well to consider first the diffusion of liquids.

FIG. 1

Take a jar *A*, Fig. 1, and partly fill it with water that has been colored with a solution of blue litmus; then pour in some dilute sulphuric acid through the funnel-mouthed tube *b*, and it will form a layer at the bottom of the vessel, changing the color of the solution from blue to red. The red stratum, or layer, will be observed to slowly increase in depth until the blue color has disappeared entirely. The changing of the color is due to the action of the acid; but the slow upward progress of the red stratum is due to the diffusion of the acid in the water, and the changing of the color of the entire contents is a proof of the diffusion of the acid throughout the mass. Sulphuric acid is nearly twice as heavy as water, and if it did not mix with the water, but simply remained at the bottom of the

vessel, like so much sand, there would be no diffusion, and the blue water above the acid would retain its color.

4. The diffusion of gases is analogous to that of liquids. Suppose that in two closed vessels *A* and *B*, Fig. 2, there are different gases, and that the stop-cocks *a* and *b* are turned, thereby opening communication between the vessels; it will be found that the gases begin to mix, or diffuse, no matter what their densities may be. The mixing will continue until the composition of the mixture in both vessels is the same, unless chemical action is set up.

FIG. 2

Suppose that *B* is filled with carbon dioxide and *A* with hydrogen, and that the cocks *a* and *b* are then opened. The gas in *B*, which is nearly twenty-two times heavier than the gas in *A*, will rise against the action of gravity and diffuse with the hydrogen in *A*, and hydrogen will likewise descend into *B* and mix with the carbon dioxide.

5. When two gases are separated by a porous body an interchange takes place between them, the composition of the gas on each side of the porous body ultimately becoming the same. The rapidity with which various gases in a mixture will pass through a porous body will vary considerably, as the lighter gases pass through the pores with greater rapidity than the heavier gases. For example, fill the glass jar *A*, Fig. 3, with carbon

FIG. 3

dioxide; tie a bladder *b* over its mouth, as shown, and then place it under a bell jar *B* filled with hydrogen gas and having its mouth sealed in mercury contained in a shallow pan *C*, so as to make it air-tight. Diffusion will take place between the gases on both sides of the bladder. The hydrogen will pass into the vessel *A* through the pores of the bladder more rapidly than the carbon dioxide can pass from *A* to *B*. This, of course, means that the bladder will be bulged upwards to compensate for the increase in volume of the contents of *A*. If the jar *B* is filled with carbon dioxide and the jar *A* with hydrogen gas, the action will be reversed. Hydrogen gas will flow more rapidly from the inner jar than the carbon dioxide will flow into it, and the bladder will be distended inwards, instead of outwards, as shown in the figure.

6. From the three experiments given in Arts. **3**, **4**, and **5** are obtained three valuable lessons pertaining to the ventilation of closed spaces by diffusion of gases. Through the first experiment it is learned that gases, or exhalations, will diffuse with the air in a room and tend to form a mixture having a uniform composition at all parts of the room.

The second experiment teaches that if a window in a room is open, foul air or respired gases are removed from a room by diffusion with the outer atmosphere. This method of ventilating a room is necessarily slow; the rapidity of diffusion, however, will vary. It will increase with an increase in the contamination of air in the room, that is to say, the ventilating, or diffusing, influence will increase with the vitiation of the air. This is the reason that the continued vitiation of the air in an inhabited room, ventilated only by diffusion through open windows and doors, and having no air-currents, will soon cause the atmosphere of the room to reach a point where the rapidity of diffusion, that is, the quantity of foul air passing into the outer atmosphere, or the quantity of fresh air entering the room to correspond with the diffusion of foul air, will exactly equal the vitiating effect of the occupants of the room.

The third experiment teaches that gases cannot be confined in rooms enclosed by the ordinary lath-and-plaster walls, because diffusion takes place through these porous bodies; and, if the gases separated by the walls are different combinations there will take place a change of air that tends to equalize the mixtures both outside and inside of the room.

7. Fig. 4 shows the interior of two rooms separated only by a lath-and-plaster partition of the ordinary kind. The room to the left is occupied by a person prostrated by some infectious disease, and the room to the right is occupied by an apparently healthy person. The air in the left-hand room becomes vitiated to a great extent, not only by the exhalations of the patient, but also by the emanations from his

FIG. 4

body, and all that separates this air from the air in the right-hand room are two sheets of plaster, each of which is about $\frac{1}{2}$ inch thick. Plaster is an exceedingly porous material; the gases in the left-hand room will diffuse with the air in the right-hand room, and, of course, a part of the air in the right-hand room will diffuse with that in the left-hand room.

8. Ventilation, or change of air, by diffusion, is at the best a slow process of changing the air of a room unless the openings that permit of diffusion are very large. The most positive and most effective method of ventilating a room is to have actual air-currents, due to fresh air entering and to foul air leaving the room. By reason of these currents an

actual displacement of foul air by fresh air is obtained and the degree of vitiation can be regulated by simply regulating the volume of air entering or leaving the room.

DISTRIBUTION AND CIRCULATION OF AIR

9. It may easily happen that the ventilation of a room will be very unsatisfactory, notwithstanding that a current of fresh air of sufficient quantity is constantly passing into the apartment, with a corresponding outflow of foul air. Unless the incoming air is introduced in a proper manner, it may pass in a nearly unbroken current from the inlet to the outlet and practically fail to disturb and renew the main body of air in the room.

It is quite as necessary to secure thorough distribution and diffusion of the fresh air as to provide an inlet and outlet. Good ventilation requires that the foul air shall be well mixed and diluted with pure air; but whether the desired mixing will take place or not depends mainly on the care and skill employed to insure the conditions necessary for proper diffusion. Neglect at this point has led to many serious failures in ventilating buildings.

10. If warm fresh air is introduced near the top of a room it will lie against the ceiling in a body, and will not diffuse to any satisfactory extent in the colder air below. To get it down to the breathing level, it must be driven down by force; there is no other way. If the air is introduced through a register in the floor, it will quickly ascend to the ceiling and will not mix freely with the cooler air through which it passes. The tendency of ascending currents of hot air is to flow in well-defined streaks, the separation becoming more marked as the difference in temperature increases. The diffusion may be greatly improved by introducing the hot air in a large number of small streams, but this is impracticable in many cases on account of the expense involved.

The smaller the difference in temperature between two bodies of air, the more readily will the one diffuse in the other; therefore, it is always advisable to introduce the fresh

warm air at a temperature as little as possible above the desired constant temperature of the room. It is not practicable to warm a room satisfactorily with a current of highly heated air, because it cannot be made to diffuse uniformly, and one part of the room will be much warmer than another.

11. An important property of both hot and cold air-currents that is of great importance in the art of ventilation is their tendency to adhere to surfaces along which they happen to be moving. For instance, if a current flows horizontally through an opening at the level of the floor, it will keep close to the floor and be plainly perceptible a long distance away; but a similar current issuing from an opening in the wall midway between the floor and ceiling would be quite imperceptible at only a few feet in front of the register. In a similar manner, a current of cold air formed by the cooling action of a large window will, in many cases, descend and creep along the floor almost to the opposite side of the room before it diffuses, making it very uncomfortable around the feet and ankles of the occupants. In this way, annoying drafts may occur at points where they are least expected. This matter must be carefully considered in locating warm-air registers; otherwise, diffusion of the fresh air may be defeated. On the other hand, it may be practicable, under some circumstances, to utilize this property of air-currents so as to secure the delivery of air to points quite remote from the register.

Many ventilating projects in which the air has been introduced through numerous openings in the floor, or in the risers of stepped floors, have yielded very disagreeable results because this matter was not duly considered.

12. If there is a large window in the room, the air will tend to circulate as shown in Fig. 5. Being rapidly cooled by contact with the glass, it will flow downwards with considerable velocity, and the current will spread out on the floor, thus forming a cold stratum at *a*. The upward currents of air in other parts of the room, to compensate for the downward current, will be so diffused and slow as to be imperceptible. Now, if hot air is introduced through a floor

register at *c*, or a wall register at *b*, a rapid circulation will be set up in the direction indicated by the arrows, and the difference in temperature between the upper and lower parts of the room will be increased. The same result will follow if a radiator or stove is placed at *c*. But if the heater or hot-air register is located at *d*, the circulation will be reversed in

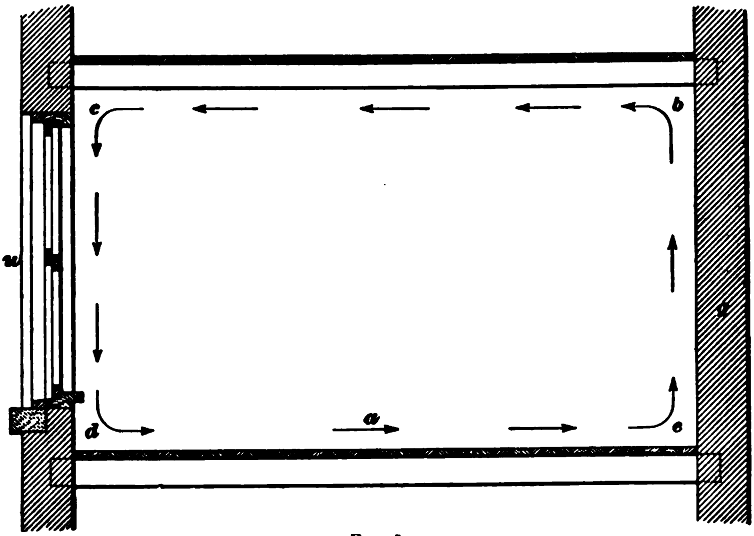


Fig. 5

direction. The air that is cooled by the window *w* will encounter the ascending current of hot air and will be carried upwards with it. The velocity of the general circulation will then be much slower than in the former case, and the results will be more satisfactory.

ACOUSTIC EFFECTS OF AIR-CURRENTS

13. It is a matter of great importance in all public buildings, such as churches, theaters, lecture rooms, etc., that a person speaking from the stage or platform should be distinctly heard at any point on the floor or in the galleries.

The transmission of sound is affected to a considerable degree by currents in the air, and by variations in its

density, or temperature. If a sound projected by the speaker encounters an air-current, it will be deflected from its original course, and will appear to the hearer to be somewhat weaker than it otherwise would. If a number of currents are encountered, the weakening effect will be very noticeable. The greatest obstruction, however, is caused by inequalities in the temperature of the air through which the sound passes. Sound is always retarded by passing from a denser medium into a lighter one, and from a lighter into a denser medium. When an audience room is full of streaks of warm air, either ascending or descending, the voice of the speaker will be so retarded in passing through them successively that persons in the more remote parts of the room will have great difficulty in hearing plainly.

It is well known that there is a great difference in the acoustic properties of a hall when empty and when full of people. The presence of the audience seems to weaken and obstruct the sounds made by the speaker. Part of this effect is due to the rustling and other slight noises made by the occupants, but the greater part of the obstructive effect is caused by the change in the condition of the air. Instead of its being of a nearly uniform density throughout, as was the case when the room was empty, it becomes diversified by numerous small currents of moist, warm air, one of which ascends steadily from each individual in the assembly. These, together with the hot currents rising from floor registers, gas burners, etc., make the air so uneven in density that sound travels through it with difficulty. The practice of introducing the warm air through large openings in the vertical front of the stage, or through large floor registers between the audience and the speaker's platform, is for these reasons a bad one, and should be carefully avoided.

The trouble in most auditoriums having poor acoustic properties lies in the improper shape given to the room; but, in many cases, rooms that are otherwise well designed and constructed are completely spoiled for speaking purposes by improper ventilating and heating arrangements.

NATURAL, OR GRAVITY, SYSTEM

GENERAL DESCRIPTION

14. There are many different ways of ventilating a building, that is to say, of removing the foul air and replacing it with fresh air. Generally speaking, they may be grouped together and classed under two main heads, namely, *natural*, or *gravity*, *ventilation* and *artificial ventilation*. The first-mentioned class, or **natural ventilation**, is that in which the foul air is removed from the building by natural means, that is to say, by means that exist independent of the system of ventilation, and in which machinery, or any force other than that of gravity, is not employed. In all systems of ventilation, force is required to move the air in the flues or ducts, and so long as the force is not applied by living beings, or by apparatus prepared by them for the purpose of generating the force, the system will be one of natural ventilation.

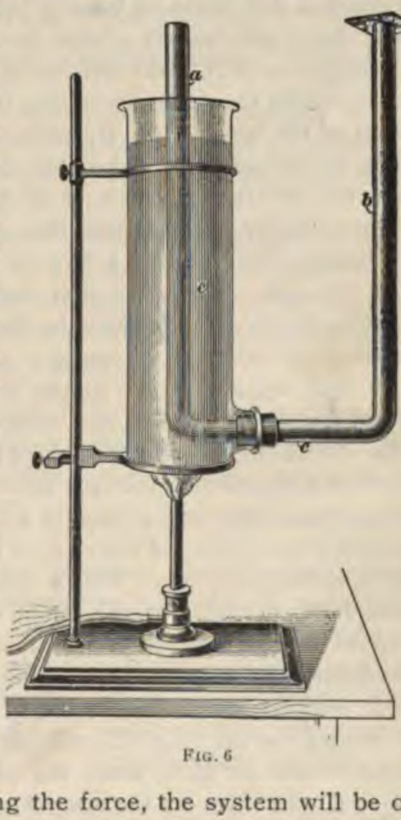


FIG. 6

15. In natural, as well as in artificial, ventilation, the movement of the air depends on pressure. Air and all fluids will flow from places of high pressure to those of low

pressure, the constant tendency of gases and liquids being to form an equilibrium of pressures.

In order to illustrate the movement of the air and thereby be better enabled to grasp the theory of ventilation, reference may be had to Fig. 6. Suppose the bent tube *a c b* to be filled with air and to have its ends open to the atmosphere. Before the air can be made to flow out of the tube, there must be a difference in pressure, or more properly speaking, a difference in density between the air in *a* and *b*. When the mean density of the air in *a* is precisely equal to that of the air in *b*, there will be no flow of air through the tube, because the pressure at the base of *a* is exactly equal to that at the base of *b*. If, however, the density of the air in one of the columns is greater than that of the air in the other, the pressure at the base of the denser column will be correspondingly greater than that at the base of the other, and, hence, there will be a flow of air toward the space of lower pressure. To prove that there will be a difference in pressure due to a difference in density, apply heat to the column *a* by heating the water *e* surrounding it, and place an air-tight top *d* over *b*. As the air in *a* receives heat from the hot water, it expands, and some of it will be pushed out of the mouth of *a* to allow for the expansion. Since some of the air in *a* is pushed out of the tube and thus lost as regards its relation to the air column in *a*, it is evident that the air remaining in *a* is not as heavy as it was before part of it was expelled—the part must weigh less than the whole. The atmospheric pressure at the orifice of either of the tubes is equal to that at the other, because they are in the same atmosphere and on a level with one another. If the weight of the atmosphere at the mouth of the tubes is neglected, the pressure at the base of *a* will simply equal that due to the weight of the air in *a*, while the pressure at the base of *b* will equal that due to the weight of the air in *b*. But, the air in *a* is lighter than that in *b*; so it follows that the pressure at the base of *a* is less than that at the base of *b*. If the equal pressures on the tube orifices are added to these unequal pressures, the sums of the pressures will still be

unequal. To compute the difference in pressure, that is to say, the force that impels a flow of air through the tubes, assume that the tubes are 50 feet high and 1 square foot in sectional area; that the temperature of the air in *b* is 62° F., and the mean temperature of the air in *a* is 180° F. It is evident that *a* and *b* each contain $50 \times 1 = 50$ cubic feet of air, and the only difference between them is that the air in *b* is more dense than that in *a*, and consequently is heavier.

Since air expands about $\frac{1}{460}$ of its volume at 0° with every degree rise in temperature, it follows that $50 \times \frac{460 + 180}{460 + 62} = 61.3$ cubic feet is the volume at 180°, and the amount of expansion, that is to say, the amount of air at a temperature of 180° that is forced from the tube is $61.3 - 50 = 11.3$ cubic feet.

A cubic foot of air at 180° weighs .06208 pound; consequently, the weight of 11.3 cubic feet is $.06208 \times 11.3 = .7$ pound, nearly; this is the difference between the weights of the columns *a* and *b*, and is the force that causes the rarefied air in *a* to flow upwards.

16. To find the pressure, in inches, of water column, or, as it may be called, the motive force that tends to cause a flow of air through the tube in Fig. 6, the pressure, in pounds per square foot, is divided by 5.2; thus, $\frac{.7}{5.2} = .135$ inch, nearly. This is an exceedingly low pressure, but it is sufficient to cause the air to flow through the tube with a remarkably high velocity if the tube is straight and smooth inside.

Since the motive force in natural ventilation is exceedingly low, it is usually found that buildings warmed by this method are very liable to back drafts, or blow-downs; in other words, to a reversal of the direction of the natural air-currents.

17. With the natural, or gravity, system of ventilation, special arrangements are seldom employed for exhausting the foul air from the rooms. The fresh air enters at the registers by virtue of a small excess of pressure above that of the atmosphere. In the better class of dwellings, special

flues by which the foul air may pass out are provided; but, in the majority of cases, the foul air escapes only through incidental outlets, such as openings around the window casings, loosely fitting window sashes, cracks in the plastering and walls, through transoms, under doors, etc.

18. The problem of ventilation by the gravity system is always combined with the question of heating. The air is moved solely by heat, which is applied before the air enters the room, or immediately afterwards. In what is known as the aspiration system, the fresh air may be unwarmed, and the heat for moving it may be applied after it has left the room and entered the foul-air flues.

With the natural, or gravity, system of ventilation, the amount of fresh air that enters the room depends on its temperature and on the rate at which heat is lost by the cooling effect of walls, windows, etc. Usually the main object is to maintain a certain temperature in the apartment, the fresh air being regarded principally as a carrier of heat. If the cooling process goes on slowly, the quantity of hot air admitted must be reduced, regardless of the needs of ventilation. Thus, the gravity system operates to provide the greatest supply of fresh air in very cold, windy weather, and the least in moderate, still, and humid weather—just the reverse of what ought to be the case. This evil may be remedied by lowering the temperature to such a point that the whole volume of air required for ventilation may be introduced without carrying any more heat than is needed to supply the regular loss. To do this will require, in many cases, a large volume of air at a very moderate temperature, but it is impracticable to accomplish this with ordinary forms of heating apparatus, because they do not contain the requisite area of heating surface. It is much easier to heat a smaller volume of air to a high temperature; the desired volume and temperature may then be obtained by mixing it with cold air in proper proportions. The only way by which satisfactory ventilation can be secured in the natural-draft, or gravity, system is by employing this method of mixing. The volume of the

air supply can then be kept nearly uniform, while the heat can be varied as much as desired.

19. The most conspicuous and serious defect of the natural ventilation system is its weakness or lack of motive force during mild weather. If the volume of air is maintained at a proper standard, the requisite temperature will differ so little from that of the outer atmosphere that the draft will be very weak—usually too weak to operate well. If the mixing method is not employed, then either the heating will be carried too far, or the ventilation will be seriously deficient.

The need of a mixing valve arises mainly from the difficulty of regulating the heat emitted by steam and hot-air apparatus. Where hot water is used, or the vacuum system of steam heating, the heat is under perfect control, and in such cases mixing valves are not as necessary.

INFLUENCE OF WIND ON VENTILATION

20. Wind is a large atmospheric current of air moving toward an area of low pressure. In ordinary winds of moderate velocity, the movement is equal from all points of the compass toward the locality in which the pressure is below the normal. Thus, the wind may be blowing from the east at a certain point, while at another point it will be blowing just as steadily from the west. The area of low pressure does not usually remain stationary; it is apt to shift from one locality to another. In the winter season, this shifting movement is usually slow, from 20 to 50 miles per day, but in summer the movement is frequently much more rapid. The area of low pressure is really the center of a storm, which may vary in force from a gentle breeze to a heavy gale. As this center passes by any certain point, the direction of the wind at that point will change, because the movement of the air will always be toward the storm center. Thus, the wind may blow from the east in the morning, and from the opposite quarter in the afternoon of the same day.

21. The mechanical effects of the wind that are of interest in the heating and ventilation of buildings are: (1) The increase of the atmospheric pressure on the windward side of buildings, and the corresponding decrease of pressure on the opposite side. (2) The increase of the draft of chimneys and flues. (3) The reversal of currents, called **blow-downs.** (4) The formation of eddies and whirls that deposit dust and snow in undesirable places. (5) The increase of evaporation and the consequent drying and cooling effects.

22. The pressure of the wind is often employed in forcing the air to move through a ventilating apparatus; but, since the pressure varies, being greatest when the wind blows strongly, the movement of the air will not be constant. Buildings that depend to a great extent on the wind pressure for ventilation are usually too well ventilated when the wind blows strongly, and are not ventilated enough when there is no wind.

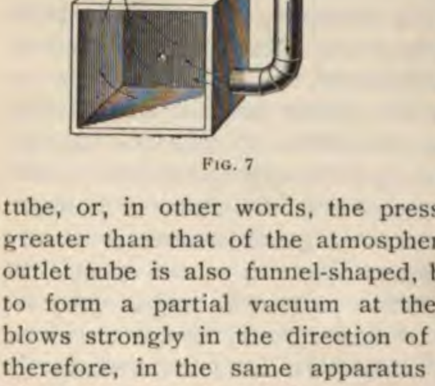


Fig. 7

Fig. 7 shows diagrammatically how air may be moved by wind pressure. The wind blows, as shown by the arrows, into the funnel mouth *a* of the inlet tube, which, of course, must face the wind. This forms a plenum in the inlet tube, or, in other words, the pressure in the inlet tube is greater than that of the atmosphere. The mouth *b* of the outlet tube is also funnel-shaped, because this shape tends to form a partial vacuum at the orifice when the wind blows strongly in the direction of the arrows. There is, therefore, in the same apparatus a plenum, or space of high pressure at *a*, and a vacuum, or space of low pressure, at *b*, and the air will flow from *a* to *b* through the

box *c*, as shown by the arrows; the air in the box is thus rapidly renewed.

The velocity with which the air will flow through the apparatus will depend entirely on the difference between the pressures at *a* and *b*, and the resistance offered to its movement by friction, change of direction, etc. Should the wind cease to blow, the circulation of air throughout the system will simply be that due to a difference in temperature between the inlet and outlet columns, as explained in reference to Fig. 6.

23. The effect of wind blowing on a building is to form an area of high pressure on the windward side, and an area of low pressure on the leeward side, and when this condition exists, the wind has a tendency to blow through the building, independent of ventilating flues and shafts. It will flow into the building through crevices around windows, doors, etc.,

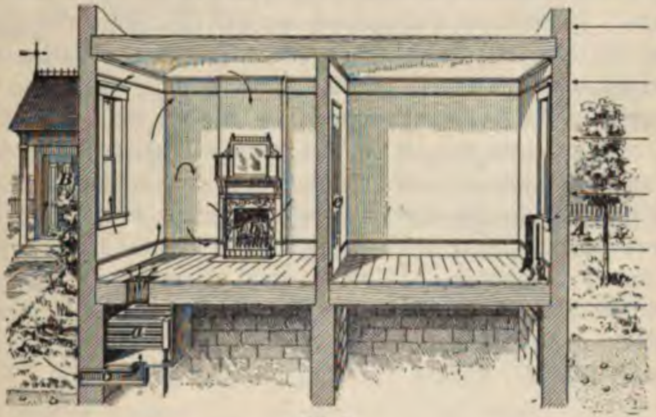


FIG. 8

and will even, to a certain extent, pass through the pores of the wall itself. This will form a plenum in the rooms, sometimes to an extent sufficient to cause a reversal of the air-currents in the inlet flues.

An illustration of this is shown in Fig. 8. The room to the left is furnished with an indirect radiator *a* suspended from the floor joists, and an open fireplace *b*. When the air-currents are flowing in their natural direction, the cold-air

duct *c* will be the fresh-air inlet and the chimney flue the foul-air outlet; the path of the currents will be about as indicated by the arrows.

When the wind blows strongly against the wall to the right, an area of high pressure will be formed at *A* and an area of low pressure at *B*. The pressure in the right-hand room will be increased slightly above that of the atmosphere, if the door *e* is tightly shut and the room otherwise closed. The pressure at *B* is below that of the atmosphere; in order that air may flow from *B* into the left-hand room, the pressure in the room must be lower still. This may be accomplished if there is a strong draft in the chimney flue. If such a draft is obtained, and the pressure in this room thereby sufficiently decreased to cause air to enter from the low-pressure area *B*, it is evident that there must be a considerable difference between the pressure of the air in the two rooms. If the door *e* is opened, air will flow from the right-hand to the left-hand room, and will thus equalize the pressure throughout the space. This, in fact, will cause the pressure in the left-hand room to rise higher than that at *B*, and consequently the air in the room will simply flow into the area of lower pressure through window crevices and the cold-air duct to the indirect radiator *a*, provided that the difference in pressure is enough to counteract the buoyancy of the hot-air column in *a*. This reversal of currents in the inlet duct will be most likely to occur if the fireplace *b* is closed or the window in the exposed wall is opened or is very loosely fitted.

24. If the ventilation of the building alone is to be considered, any blow-backs in the inlet ducts is a matter of very little importance, because the chief object to be attained is the removal of air from the building and the replacing of it with fresh air, without causing drafts. When, however, the heating of the building is a factor for consideration, and particularly when the fresh air supplied to the building must be heated before its entry, the reversal of currents in the inlet ducts becomes a very serious matter, because the hot,

fresh air is then forced to the outer atmosphere and cold air flows into the building instead. This is precisely what will happen in the case illustrated in Fig. 8 when the indirect radiator *a* is in use and the conditions are as stated.

WIND PRESSURE

25. The pressure of the wind on flat surfaces at right angles to the current, at velocities ranging from 2 to 100 miles per hour, is given in the following table:

TABLE I

PRESSURE OF WIND ON FLAT SURFACES

Velocity		Pressure per Square Foot Pounds	Character of Wind
Miles per Hour	Feet per Minute		
2	176	.030	Perceptible breeze
3	264	.055	Perceptible breeze
4	352	.085	Perceptible breeze
5	440	.133	Perceptible breeze
7	616	.245	Perceptible breeze
10	880	.523	Gentle breeze
15	1,320	1.150	Light wind
20	1,760	2.000	Light wind
25	2,200	3.160	Strong wind
30	2,640	4.500	Strong wind
35	3,080	6.100	High wind
40	3,520	7.500	High wind
45	3,960	10.125	Gale
50	4,400	12.500	Gale
60	5,280	18.000	Strong gale
70	6,160	24.500	Violent gale
80	7,040	30.200	Violent gale
90	7,920	41.000	Hurricane
100	8,800	50.000	Tornado

The pressure exerted by the wind, per square foot of projected area, is greatly modified by the shape of the surface. Thus, the pressure on a sphere, a hemisphere with its convex side toward the wind, or a cylinder, is about one-half of that on a flat surface of equal projected area.

POSITION OF INLETS AND OUTLETS

26. In order to properly ventilate a room, the fresh air should be admitted at such points and in such a manner that it will travel uncontaminated from the inlet orifices to those who are to inhale it.

To ascertain the point or points of inlet, the direction in which the exhalations from the lungs have a natural tendency to travel must first be considered, so that the inlet may be arranged to supply fresh air from the opposite direction. Suppose that two lighted candles, *a*, *b*, Fig. 9, are placed inside an air-tight glass vessel; then consider what occurs. The carbon dioxide given off by the flames diffuses with that part of the air surrounding them, and, owing to the rarefication of this mixture, due to its high temperature, it will rise to the upper part of the vessel and will remain there as long as its temperature is much greater than that of the air below it. The products of combustion from the flames will continue to ascend, and the stratum formed by them at the top of the vessel will become deeper. When it is deep enough to reach the candle *b*, the flame thus engulfed in the descending stratum of carbon dioxide will be extinguished. The candle *a* now burns alone and

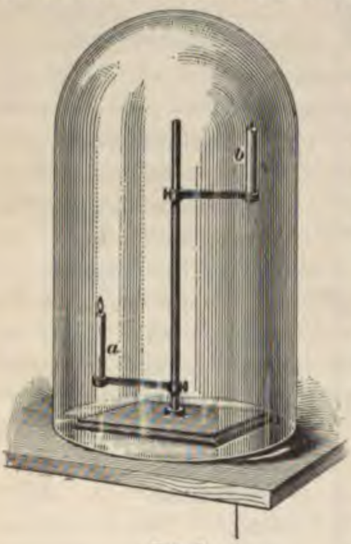


FIG. 9

increases the depth of the stratum until engulfed by it, when its flame will also be extinguished.

By this simple experiment it is seen that the impure air rises to the top and the pure air falls to the bottom, while the candles are burning. This is due simply to the fact that the temperature of the products of combustion is so high that the density of the gases is less than that of the colder air in the jar; consequently, the products rise to the top. Suppose that the jar and its contents cool, or, in other words, reach a uniform temperature throughout. The gases within the jar will diffuse and saturate one another; then, the surplus, or those volumes that cannot be thus held by diffusion, will form into strata according to their densities, the most dense collecting on the bottom and the least dense on top. It will clearly be seen, that in order to properly carry off the products of combustion from the burning candles, an outlet should be formed in the top of the vessel; and that to permit fresh air to enter and take the place of the vitiated air passing out through the top, an opening should be made at the bottom of the vessel.

27. The principle explained in Art. **26** holds good in ventilating rooms, auditoriums, etc., when the density of the exhalations is less than that of the air surrounding the occupants. It is thought by many that air exhaled from the lungs is entirely composed of carbon dioxide, but the quantity of carbon dioxide in exhaled air is very small compared with the volume of nitrogen present; and, since nitrogen is lighter than air, it will easily be seen that the weight of exhaled air must be nearly the same as the weight of fresh air having the same temperature. Whether the density of the exhalations is greater or less will depend on the temperature of the air. The temperature of exhaled air is about 95° F. as it enters the room, and if the temperature of the air around the person is 70° or less, the density of the exhalations will be less than that of the air; consequently, they will rise. Tests have demonstrated the fact that the point of maximum vitiation in rooms occupied by human beings,

and particularly those in which gas flames are burning, is near the ceiling. This is made more evident if the air in the room is not agitated.

From this, it seems reasonable to infer that for the proper ventilation of crowded rooms the outlet for the warm vitiated air should be near the ceilings, and the inlets for the fresh air should be in or near the floors, so that the exhalations may have a direct and natural flow to the outlet or vent flues, as shown at *A*, Fig. 10, which shows the interior of a room occupied by two persons. It shows how, by having numerous inlets *a*, *a*, etc., and an outlet *b*, a direct current flowing

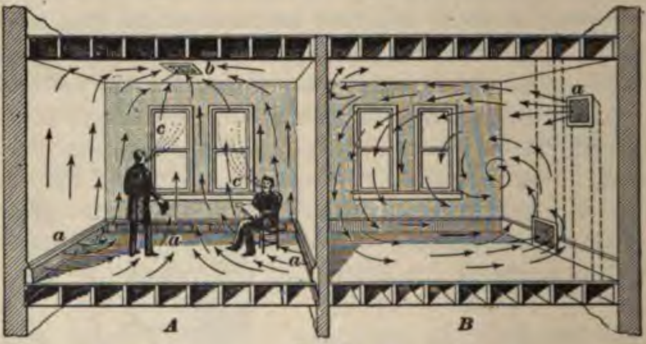


FIG. 10

with low velocity toward the outlet will carry off the exhaled air *c*, *c* and prevent it from mixing with the air in the lower part of the room. If the air is allowed to enter at a temperature much higher than about 75° or 80°, it will immediately ascend to the ceiling and displace the foul air, which will fall by gravity toward the floor, and the fresh warm air will then flow out of the vent flue almost uncontaminated. The air inlets must be numerous, and should, if possible, be equally distributed throughout the room. The velocity of inflow should be not more than 4 feet a second, so that drafts may be avoided, and the temperature of the warm air entering the room should be less than that of the breath.

28. A system of bottom inlets and top outlets is necessarily expensive, not only in the first cost, owing to the

many inlets, but also because of the large amount of fuel required during cold weather to compensate for the quantity of heat that passes out through the vent flues with the vitiated air and is lost. To overcome this difficulty, the system of bottom outlet and top inlet shown at *B*, Fig. 10, was devised. By this method, hot air enters the room through *a* and simply churns the air around as shown, thereby mixing together the fresh and foul air, and thus diluting the impurities to a degree suitable for healthful respiration. It will be observed that by this method the temperature of the air as it leaves the room is low, because the air is taken from the floor, which is the coldest part of the room, by the lower vent flue; consequently, a saving in fuel is effected. This method is commonly used in the ventilation of schools, etc., particularly where fans are used to force a movement of the air. By this method of maintaining a suitable degree of purity, an enormous quantity of pure air is lost by passing out of the vent shaft with the exhalations. In fact, the foul air passing out through the vent shaft is practically as pure as that in the room.

VENTILATION WITH DIRECT RADIATION

29. Good ventilation is not practicable in a room heated by a direct radiator or common stove, unless additions be made that virtually change the method of heating from the direct to the direct-indirect system.

In order to secure even a tolerable degree of ventilation, a definite outlet must be made for the foul air. This is as necessary as a special inlet for cold air. To secure ventilation with direct radiation, the best plan is to provide both a positive inlet and outlet, and to supply each with a suitable damper. If the room does not possess a flue that can be used to carry off the foul air, one must be provided in some way. Usually a flue of tin or wood can be run up alongside one of the interior walls, through the floors, and into the attic. The lower ends or inlets of such flues should open within a foot of the floor.

30. A practicable method of modifying an ordinary direct-heating system so as to get a fair amount of ventila-

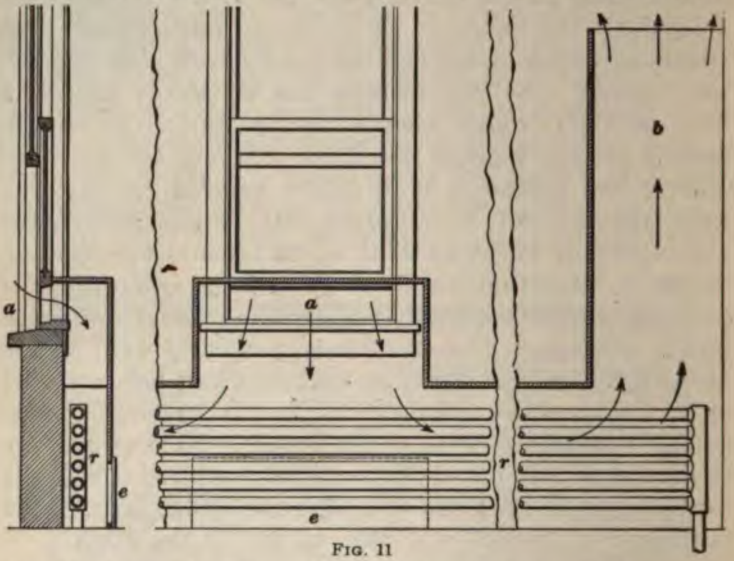


FIG. 11

tion, is shown in Figs. 11 and 12. The room is heated by means of pipe coils running along the outer walls. To secure ventilation, the coils are enclosed as shown. Fresh air is taken in through the windows at a, and after passing along over the hot radiator pipes r, is delivered through the vertical flues, as b, into the upper part of the room at the corners b', Fig. 12. The flues b should be about 8 feet high, and should be located in the outer corners of the room, as indicated in Fig. 12. The foul-air outlets may be located along the inner walls, as shown at c.

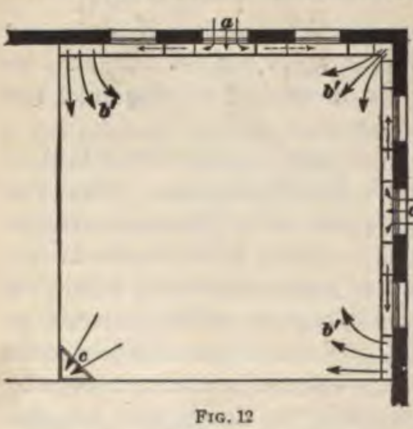


FIG. 12

In order to heat the room before it is used, and without admitting any fresh air, a door should be provided in the pipe casing, at about the middle of its length and at the level of the floor, as shown at *e*, Fig 11. This door being opened and the window closed, a good circulation will ensue and hasten the warming process.

31. Ordinary direct radiators may be treated in the way described in Art. **30**; usually, however, it is easier to cut a hole through the wall, and convert them into indirect apparatus.

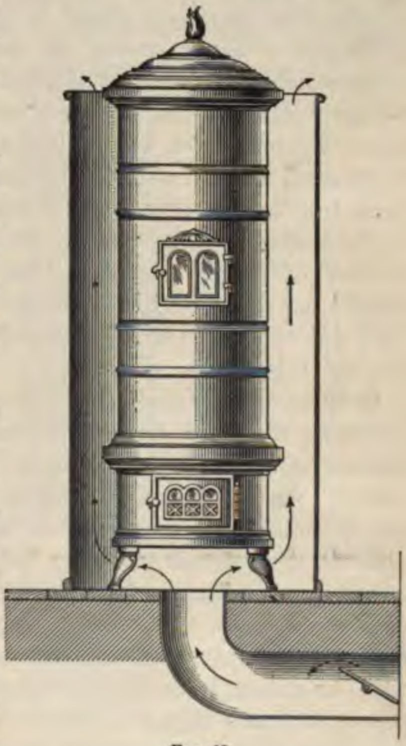


Fig. 13

Where an ordinary stove is used for heating, the ventilation may be provided for by enclosing the stove in a jacket of sheet iron or zinc, and connecting the space between them with a fresh-air duct in the floor, practically as shown in Fig. 13. It is difficult to arrange a mixing valve in this case that would repay one for the expense incurred. The temperature must be controlled by regulating the fire. Of course, an adequate and properly arranged outlet for foul air must be provided, as in all other cases.

REGULATION OF AIR SUPPLY

32. Mixing valves are indispensable to the success of any system of ventilation, except where hot water or the vacuum steam system may be used for heating; otherwise,

there is no practicable way of regulating the temperature and at the same time securing an unvarying amount of fresh air.

Notwithstanding the fact that registers having louvers, or valves, that can be opened or closed for controlling the admission of air to rooms, are almost universally used with indirect-heating apparatus of all kinds—steam, hot water, and hot-air furnaces—yet they are radically defective in a most important particular, viz., that they do not permit the heat to be shut off without shutting off the supply of fresh air at the same time. Mixing valves, on the contrary, permit the heat to be varied to any extent desired without affecting the volume of the air supply. The ordinary type of register should not be used except where it is actually necessary to vary the volume of fresh air admitted, or to entirely shut off the air supply.

In large rooms supplied with fresh air at several points, it is desirable that each flue should be provided with a separate mixing valve, so that the temperature of the several air-currents may be varied independently when required. During the prevalence of very cold or windy weather, it is usually difficult to maintain an even temperature on both sides of the room; but if the apparatus is arranged as advised, the difficulty may be overcome by introducing the warm air at a higher temperature on the exposed side than on the other.

In hospitals, it is usually required that the flues be so arranged that a high local temperature may be maintained at any one of the beds, without regard to the temperature prevailing in the other parts of the ward.

33. Mixing valves are constructed in a great variety of ways to suit different situations, but the principle involved is the same in all. Two forms are shown in Figs. 14 and 15.

Fig. 14 shows the mode of applying a mixing valve to an ordinary direct radiator or heating coil. The coil is enclosed in a box lined with metal, extending upwards to about the level of the window sill. The box is divided into two parts, the inner one forming a channel for the upward passage of

the cold air. The damper *a* is hinged to the partition as shown, and is balanced by a weighted handle on the end of its spindle. When it is desired to heat the room without introducing fresh air, the damper is turned down to its lowest position, shutting off air from the radiator, and the inflow of cold air is stopped by shutting down the hinged cover *b*. The door *d* in the front of the box is next opened, and the radiator then operates by ordinary circulation of the air in the room.

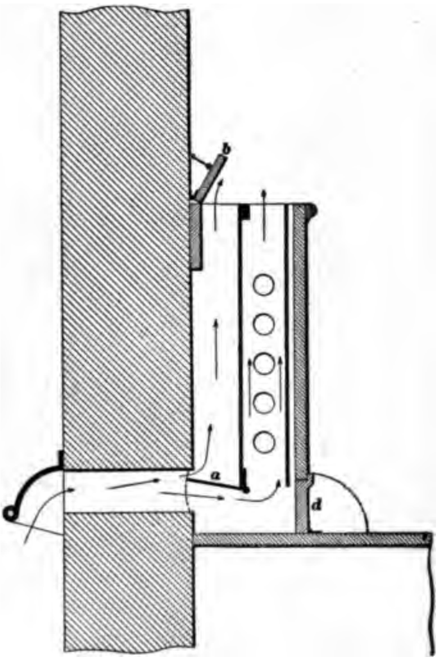


FIG. 14

The importance of the improvement in ventilation to be made by using these devices is not understood or appreciated, either by the public, which is vitally interested in the matter, or by the architects and others who supply heating apparatus. An eminent sanitarian, Dr. John S. Billings, says of mixing valves: "They should be used much more extensively than is at present the case, and it is in this direction that the most immediate and important improvement of ventilation of dwelling houses, in this climate, can be effected."

34. Fig. 15 shows the application of a mixing valve to an indirect radiator. The radiator is enclosed in the case *a*, and is supplied with fresh cold air by the duct *b*. Warm air is delivered through *d* into the flue, as shown by the arrow. The duct *b* is connected to *d* by a by-pass pipe *c*, and the opening is controlled by a valve *v* that is hinged as shown.

This valve permits more or less cold air to pass directly into the flue without passing over the radiator. The flow of air through the radiator box *a* is checked to the extent that air is allowed to pass up the pipe *c*. The area of the opening of the valve *v* usually does not require to be more than one-third to one-half that of the vertical duct.

The mixing valve should be located at the foot of the vertical duct, and it may be operated from any floor by means

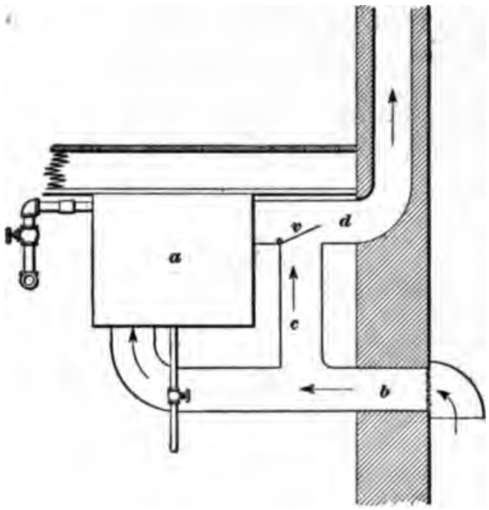


FIG. 15

of suitable connections. These are usually made of brass wire and chain, brass being used to avoid breakage by rusting. If desired, the connections may pass down through the flue.

All mixing valves should operate to change the proportions of the hot and cold air, without affecting the volume of the currents of air passing into the rooms.

CAPACITY OF HOT-AIR FLUES AND REGISTERS

35. Size of Flues.—The air-carrying capacity of a natural-draft flue or duct is controlled by the temperature of the hot air and the height of the flue, in the same manner as a chimney. A flue that extends to the third story of a building

will discharge more air per minute than a similar flue that discharges at the second or first floor. This is because the column of hot air extending to the third floor is higher than the others, and consequently the upward pressure is greater.

In practice, the flow per minute will be considerably less than the theoretical amount, because of the frictional resistance in the flues. The allowance to be made for friction

TABLE II

FLOW OF AIR IN FLUES UNDER NATURAL DRAFT

Difference in Temperature Degrees Fahrenheit	Height of Flue in Feet								
	10	15	20	30	40	50	60	80	100
	Discharge in Cubic Feet per Minute								
10	108	133	153	188	217	242	264	306	342
15	133	162	188	230	265	297	325	375	420
20	153	188	217	265	306	342	373	435	485
25	171	210	242	297	342	383	420	485	530
30	188	230	265	325	375	419	461	530	594
40	216	265	305	374	431	482	529	608	680
50	242	297	342	419	484	541	594	680	768
60	266	327	376	460	532	595	650	747	842
70	288	354	407	498	576	644	703	809	910
80	308	379	435	533	616	688	751	866	972
90	326	401	460	565	652	728	795	918	1,029
100	342	419	484	593	684	765	835	965	1,080
125	384	470	541	664	766	857	939	1,085	1,216
150	419	514	593	726	838	937	1,028	1,185	1,325

varies for each situation. In Table II, 50 per cent. has been deducted from the theoretical flow; this will be sufficient for all ordinary circumstances. It should be borne in mind that the volume of flow shown in the table cannot be attained unless the air in the room is permitted to escape freely

and as rapidly as the fresh warm air is inclined to come in. Table II gives the flow of air in cubic feet per minute.

The difference in temperature given in the table is that existing between the outer atmosphere and the average of the air in the flue.

36. The required area of a natural-draft flue is found by multiplying the number of persons in the room by the volume of air supplied to each person per minute, and dividing the product by the flow of air per minute corresponding to the temperature difference and height of flue, as taken from Table II. The quotient will be the sectional area, in square feet. Thus, suppose that it is required to find the sectional area of a natural-draft flue 50 feet high that is intended to remove the vitiated air from a room containing 25 persons, and that each person is to be supplied with 30 cubic feet of fresh air per minute, the temperature of the air in the flue being 70° F. and the outdoor temperature 30° F. The temperature difference in this case is $70 - 30 = 40°$. By consulting Table II the air velocity is found to be 482 feet per minute. Then, the sectional area of the flue is $\frac{25 \times 30}{482} = 1.56$ square feet, nearly.

37. Several vertical ducts may be supplied by a single horizontal main pipe or flue, although they vary in height. The flow in each duct may be regulated by partly closing the opening at its foot.

The cooling effect of the surroundings of a hot-air duct should always be taken into consideration when determining its dimensions. In a long duct, the average temperature is likely to be lower than in a short one, because of the greater loss of heat. The reduction of the average temperature decreases the rate of flow, and the dimensions must be modified accordingly.

Hot-air pipes are commonly made of bright tin, it being supposed that the bright surface of the metal will prevent the escape of heat to a considerable degree. The retarding influence of the bright surface is, however, quickly spoiled

by a coating of fine dust that is deposited on it, and the chief benefit of the tin coating is to prevent rust and to preserve a smooth surface. The best way to prevent loss of heat is to cover the pipes with non-conducting materials.

38. Size of Registers.—Each register should be supplied by an independent vertical duct. Sometimes it is practicable to supply two or more registers located at the same level by means of one duct, but generally such arrangements

TABLE III

NET AREA OF SQUARE REGISTERS

Size of Opening Inches	Net Area Square Inches	Size of Opening Inches	Net Area Square Inches
6 × 10	40	14 × 22	205
8 × 10	53	15 × 25	250
8 × 12	64	16 × 24	256
8 × 15	80	20 × 20	267
9 × 12	72	20 × 24	320
9 × 14	84	20 × 26	347
10 × 12	80	21 × 29	406
10 × 14	93	27 × 27	486
10 × 16	107	27 × 38	684
12 × 15	120	30 × 30	600
12 × 19	152		

are liable to be unsatisfactory. It is difficult and usually impracticable to supply registers on different floors from a single vertical flue. The upper registers will discharge a large proportion of air, and the flow from the lower registers will be too small unless some means is employed to regulate the flow.

The area of a hot-air register should be sufficient to permit the desired quantity of air to pass into the room at a velocity not exceeding 4 feet per second. The velocity of the air in the flues may be as great as desired, or as the circumstances will permit, but the current issuing from the register must be

reduced to, or less than, the velocity given. This may be done by enlarging the flue where it approaches the register. The velocity of the current in any particular part of the flue will then be inversely proportional to the area of the flue at that point. Thus, if the air in a flue having 1 square foot of sectional area moves with a velocity of 8 feet per second, its velocity will be reduced to 4 feet per second in any part of the flue where the area is increased to 2 square feet. The enlargement of the flue at the register box should be made gradually, and with round corners, if practicable.

TABLE IV

NET AREA OF ROUND REGISTERS

Diameter of Opening Inches	Net Area Square Inches	Diameter of Opening Inches	Net Area Square Inches
7	29	18	170
8	33	20	209
9	42	24	301
10	52	30	471
12	75	36	678
14	102	48	1,206
16	134		

39. Tables III and IV show the average net or effective area of ordinary square and round registers, and are calculated on the assumption that the net area is two-thirds of the gross area.

ASPIRATION SYSTEM

GENERAL DESCRIPTION

40. In the **aspiration system** of ventilation, all the foul-air flues are brought together and connected into a single large chimney or shaft, so that there is practically only one outlet. There are in vogue three methods of arranging the flues for securing an outgoing movement of

the vitiated air: (1) To carry a separate flue from each room to the attic, where the flues converge into a few large ones and finally enter the base of the aspirating chamber or shaft, which does not extend through the lower stories. (2) To carry each foul-air flue horizontally and connect it directly into an aspirating shaft that extends through the entire building. (3) To carry the vent flues downwards into the basement, and connect them to the aspirating shaft at the lowest practicable level.

41. In the first and third methods, the number of flues increases with the height of the building, being most numerous in the upper story in the former case, and in the first story in the latter case. In high buildings, the lower walls must have considerable thickness to secure the necessary strength, and the presence of any considerable number of flues makes it necessary to increase the thickness of the walls. In many cases, this increase is very inconvenient and objectionable. On the contrary, the walls in the upper stories are naturally much thinner, and the thickening necessary to include the flues is unobjectionable.

When the flues are carried horizontally, as in the second method, it is often difficult to extend them across corridors and hallways without making an unsightly construction, the floor girders being in the way.

An aspirating chimney that extends to the basement is necessarily much more expensive than one that begins at the attic. An attic aspirating chamber may be built of wood and lined with tin, or may be made of light plate iron; but an aspirating shaft running from the basement to and through the roof is usually built of brick. The space required for a brick chimney of this kind is considerable, not only on account of the thickness of the walls required in the lower stories, but also because the sectional area necessary to carry the foul air and allow for frictional resistance is so large.

In practice, the velocity of the air will seldom exceed 6 feet per second, and the area of the shaft should be calculated on

that basis. In cases where an exhaust fan or steam-jet exhauster can be used, the estimate of velocity may be increased to 8, or possibly 10, feet per second.

The principal advantage possessed by the third method over the first is the facility that it affords for using heaters at the base of the stack to aid the draft. A part of the increase in draft pressure gained in that way is expended in overcoming the resistance offered by the foul air while descending the flues to the basement; consequently, the net gain is not very great.

When an aspirating fan or a steam-jet exhauster is employed to increase the draft instead of a heater of some kind, the advantage of cost and convenience is largely in favor of the first or upward method.

42. When the flues must be grouped in the attic, with long horizontal runs, aspirating coils are necessary in order to overcome the resistance to the passage of air through the ducts.

To arrange the vent flues so that they discharge into an open attic space is not regarded as satisfactory, because such space is cold, as a rule, and subject to the effect of winds to such an extent as to interfere seriously with the ventilation of the building. The vent flues should never open directly into an attic or roof space, unless a fan is provided for discharging the vitiated air from such roof space into the outer atmosphere. If an exhaust fan is used, the switch or valves by which its operation is controlled should be located in some convenient position in the basement, so that the janitor or engineer in charge may have no excuse for neglecting the apparatus. When an exhaust fan is not used, the foul-air ducts should discharge into an aspirating chimney carried upwards through the roof and properly capped to prevent down drafts and ingress of rain and snow. In some cases, the vent ducts are gathered together in the attic, where they discharge into a central chamber in which an aspirating coil is arranged to create the draft necessary to carry the vitiated air to the outer atmosphere. The controlling valves for the

aspirating coil should be placed in the basement, to which the water of condensation should drain freely.

43. The draft induced by an aspirating coil depends on the difference in specific gravity that its use creates between the outer air and that within the central chamber. Considering the fact that with an aspirating coil in the attic the heat is applied practically at the top of the vent flue, the influence of the heat in increasing the difference in specific gravity or weight between the exhaust or vitiated air inside and the fresh air outside is very small; so much so, in fact, that the amount of coal burned to produce the heat given off by the aspirating coil, if put into power to operate an exhaust fan, would do many times more work. It is apparent, then, that the heating surface used in aspirating vent flues should be placed near the base of the flue. In some cases, the vent ducts are carried downwards to the basement, where they discharge into a main ventilating flue, at the base of which is a large amount of heating surface. This is more economical than having the aspirating coil in the attic.

The object sought in the use of a central aspirating coil in the attic in combination with coils in the wall flues is to obviate as far as possible the retarding effect due to the chilling of the vitiated air in passing through the flues. It has been found, in practice, that there is a considerable loss of heat as the air passes to the main outlet in the attic through the galvanized-iron ducts gathered into it. While there is a positive upward movement in the flues, there is a considerable retardation to the flow of air due to cooling, so that the central aspirating chamber, toward which the flues pitch upwards, is provided to lighten or expand the air, creating a lessened pressure at the head of the ducts and thereby insuring a more positive flow of air therein.

AUXILIARY ASPIRATION APPARATUS

44. During cold weather, the difference in temperature between the foul air and the outer atmosphere is usually sufficient to create a satisfactory draft in the vent shaft; but

during mild weather, the temperature difference diminishes, and in summer it dwindles to almost nothing, on some occasions being actually reversed. The vent shaft thus becomes impotent and inoperative as the weather becomes warmer, and auxiliary apparatus must then be employed to aid in maintaining the draft required in order to secure proper ventilation. The auxiliary apparatus employed for this purpose consists of steam coils, stoves, grates, or gas burners, located at the base of the stack.

45. Steam coils, in order to be effective, should be placed crosswise of the foul-air current, and the pipes should be spaced wide apart, so as to impede the current as little as possible. The requisite number can be used by placing them in several tiers; 1¼-inch pipes should be spaced not less than 4 inches apart between centers.

If the coils are located in the aspirating stack, they should be placed horizontally, about as shown in Fig. 16, care being taken to insure perfect drainage. It is poor practice to arrange steam coils vertically and around the sides of the stack, because only a small part of the air will then come into actual contact with them and be heated.

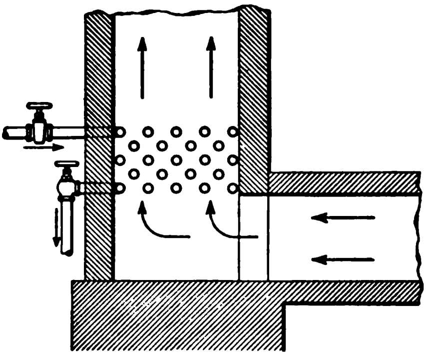


FIG. 16

The coils should be placed as low down in the stack as practicable, in order to secure the greatest available height for the column of warm air; every foul-air inlet should enter below, and not above the coils, if possible.

46. Common stoves and basket grates are very inefficient apparatus for a vent stack. They are generally set up in the bottom of the stack, and it is assumed that, because they are in a current of air, they will have plenty of draft.

This is a mistake, however, the pressure of the air being practically the same both above and below the fire; the air is driven through the fuel only by the momentum of the current. The combustion is very imperfect, and the amount of heat developed is much less than in a similar stove having a good draft. The area of heating surface is so limited that only a small portion of the air-current can come into contact with it. The hot gases of combustion ascend a long distance in the chimney before they give up their surplus heat to the air surrounding them. Thus the actual absorption of heat is so tardy that the average temperature throughout the stack is likely to be considerably less than if an equal amount of heat had been communicated by a coil at the bottom of the aspirating shaft. If a stove or grate must be used at the base of an aspirating stack, it should be provided with a smoke pipe extending a sufficient distance upwards within the stack to secure a good draft.

47. The use of ordinary gas burners to aid the draft in an aspirating flue is an exceedingly crude and wasteful method of applying heat. In order to develop the maximum amount of heat, the gas should be burned in a Bunsen burner of some kind, and to apply the heat effectively, it should be absorbed by some metallic body having a large area of emitting surface, and thence be imparted to the air at a comparatively low temperature.

48. When it is desired to diminish or control the discharge of air from an aspirating chimney by means of a valve or damper of any kind, the damper should be located at or near the top of the stack and not at its base. When the air is partly shut off at the bottom, the current passing up the stack is so weak that it is liable to be neutralized or reversed by cold contrary currents flowing down the interior.

The method of checking the draft by admitting cold air into the flue from outdoors is not to be recommended. It cools the chimney so that the draft becomes very uncertain, and may fail altogether at times.

49. If the building is a high one, and has a central hall with stairways running to the top story, there is likely to be

a strong draft up the stairs, which will antagonize the draft of the aspirating chimney. The only way to obviate this trouble is to build partitions across the hall, and thus cut off the upward circulation.

COWL VENTILATION

50. The term **cowl** is applied in a general way to all apparatus or fixtures that are placed over the top of ventilating flues, chimneys, etc. to aid the draft. They serve to protect the ascending current of hot air or gases within the flue from the influence of contrary wind currents, that might oppose or even overbalance and reverse the direction of flow therein. Cowls also serve to facilitate the escape of the warm air or gases into the area of lower pressure, which always exists on the leeward side of the ventilating shaft or chimney while the wind is blowing. The principal use of a cowl is to prevent the wind from blowing down the ventilating shaft or chimney, and to keep out the rain and snow. A properly constructed cowl will utilize the force of the wind to increase the draft, but it operates in that way only while the wind blows. During calm weather, it is always more or less of an obstruction. All claims that a cowl of any kind will aid the draft in still air are fallacious.

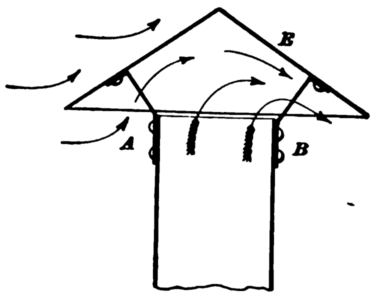


FIG. 17

Ventilation is most needed when the atmosphere is still and humid, and at such times a cowl is not only useless but is positively detrimental. Therefore, cowls should be used only in places where they are needed to prevent back drafts or blow-downs, and keep out rain or snow.

51. The plain cowl E, shown in Fig. 17, protects the flue from all possible blow-downs. The direction of the wind currents is indicated by the plain arrows, the course of the foul air or chimney gases being indicated by feathered

arrows. The cone serves as a barrier between the top of the rising column of gases and the current of wind that may be blowing crosswise or downwards, preventing any considerable interference between them. The ascending column of foul air is not compelled to lift or deflect the currents of wind, as it must do when the chimney is uncovered. The diameter of the cone should be from 2 to $2\frac{1}{2}$ times that of the pipe to which it is attached, and the distance from the edge of the pipe to the under surface of the cone should not exceed one-half the diameter of the pipe.

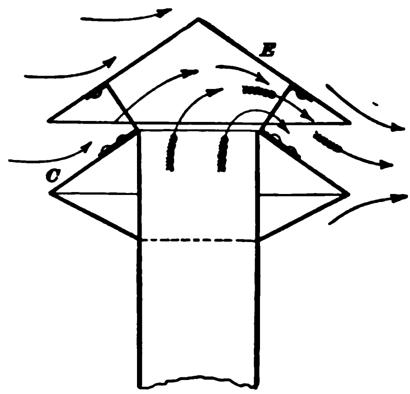


FIG. 18

The plain cowl may be improved by adding to it a deflecting collar, as shown at *C* in Fig. 18.

52. The maximum efficiency of the cowl may be attained by combining with it several secondary cones, as shown at *F* and *G* in Fig. 19. This construction is quite bulky, and it offers considerable resistance to the wind; consequently, the area of low pressure on the leeward side *B* is quite large, and the pressure is correspondingly low. The passage of the foul air or gases out of the vent shaft or chimney into the partial vacuum thus formed is very easy and direct.

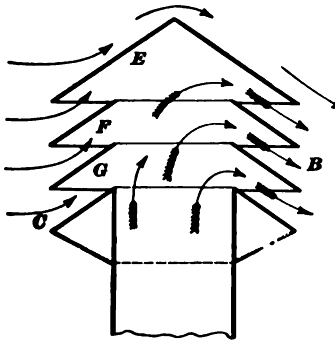


FIG. 19

53. The wind may be utilized to drive a current of air downwards in a pipe, such as an inlet or supply pipe. Fig. 20 shows an arrangement for this purpose. The pipe is provided

with a funnel *a* and a cone *b*, having its apex downwards. A part of the wind that strikes the cone will be deflected downwards into the pipe, as shown by the arrows. There will be an area of low pressure at *B*, and a part of the contents of the pipe will escape into it and so out of the pipe, as shown by the dotted arrow; consequently, some of the air will be lost. The device is called an **induction, or blowing, cowl.**

54. The cowl shown in Fig. 21 is composed of a series of vanes *a*, set at an angle to the radius of the circle, as shown in the cross-section. They are attached to two collars, *b* and *c*, and the openings between their inner edges afford an exit for the foul air or chimney gases. The plain arrows show the course of the wind currents, and the feathered arrows show how the vitiated

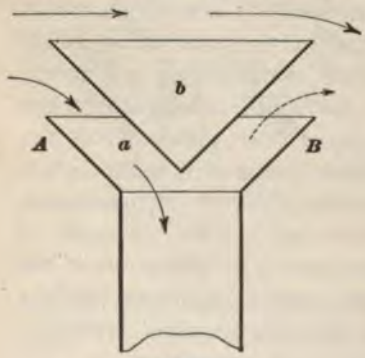


FIG. 20

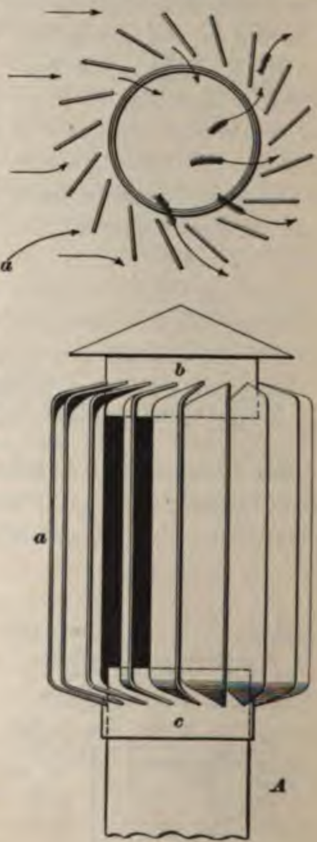


FIG. 21

air or chimney gases escape into the area of low pressure.

The wind currents are deflected advantageously on one side only, but the escaping gases are protected from interference to a considerable extent.

Sometimes this apparatus is mounted on a pivot, or a central spindle, and is allowed to rotate; but it is doubtful if any advantage is gained thereby.

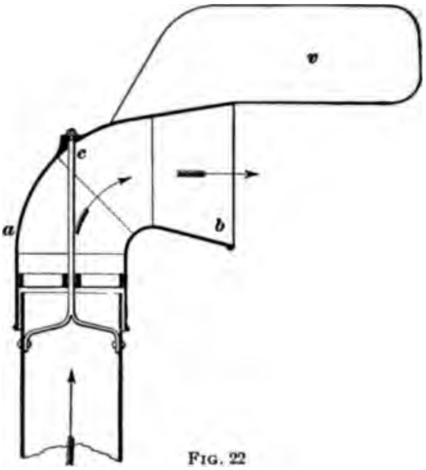


Fig. 22

55. Automatic cowls are commonly made as shown in Fig. 22. An elbow *a*, having a funnel mouth *b*, is mounted so as to turn freely on a central spindle *c*, as shown. The vane *v* catches the wind, and operates to keep the funnel always turned from the wind. This device for aiding the draft of vent flues and chimneys is very effective, but it is difficult to maintain in good working order. The pivot corrodes so rapidly that the elbow is apt to stick fast and fail to operate.

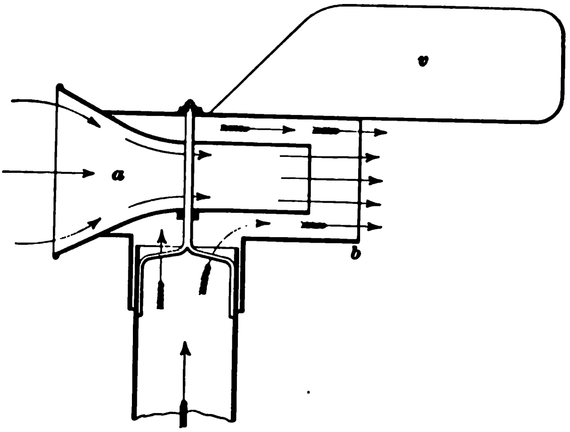


Fig. 23

This apparatus may be used to produce a downward current, for ventilating purposes, by changing the vane *v* so that

it will hold the funnel toward the wind instead of away from it.

56. The cowl shown in Fig. 23 is provided with a blowing cone *a* that causes the cowl to operate as an ejector. The wind caught by the cone gathers into a small current of high velocity, and as this current emerges into the mouth of the elbow or tube *b* it communicates its velocity to the foul air or gases at the top of the shaft, forcing them ahead with it, and creating a partial vacuum around the cone. The foul air or gases from below then rushes upwards with an augmented velocity, owing to the increased difference of pressure. This apparatus is called an **automatic eduction cowl.**

VENTILATION OF DWELLINGS

GENERAL REQUIREMENTS

57. The number of people occupying an ordinary dwelling is usually quite small, while the area of windows and other cooling surfaces is relatively larger than in any other class of buildings. Consequently it happens, in many cases, that the volume of air required for respiration is less than that needed to maintain the temperature.

It is impracticable to ventilate a dwelling in a proper manner when direct heaters of any kind are used for warming it. The heaters, whether stoves or radiators, must be converted into direct-indirect or indirect apparatus; and the foul air must be vented positively and continuously. The inlets and outlets of each room must be so placed and adjusted that there will be no considerable difference of temperature in any part of the room. These results can be attained only by employing some system of aspiration, mechanical ventilation being assumed to be impracticable on account of expense of installation and maintenance. Foul-air ducts of suitable size, and having sufficient height to draw well, must be provided; they are, in fact, indispensable. These ducts should be brought together and connected into a good chimney. The smoke pipe from the kitchen stove or the heating

apparatus should extend through this chimney such a distance that there will be no chance of having a poor draft for the fire. The pipe inside of the chimney should be made of cast iron, to withstand corrosion, and it should be braced so as to stand in the center of the flue rather than at one side. It is better to make one large flue, with a smoke pipe inside of it, than to build a pair of flues, one for foul air and the other for smoke. In all but the smallest dwellings, two such foul-air chimneys should be provided, one taking the smoke pipe from the kitchen range, and the other from the furnace or boiler. This permits the foul air to be disposed of with a minimum amount of piping. The doors and windows should be made as nearly air-tight as possible, so that cold air cannot enter the building except through the proper channel, that is, through the heating apparatus.

58. One of the chief difficulties to be found in securing a proper distribution of warm air in the several stories of a dwelling is the draft that always exists to a greater or less extent on the stairway. An upward current of considerable force prevails there at all times while the heating apparatus is in use, and if there is any way of escape for air at the top, this draft will be so strong as to interfere with the proper suction of the foul-air flues. While this trouble may be avoided by enclosing the stairs and placing doors at the foot or head, this remedy is usually so much objected to that it may be dismissed as impracticable.

If one side of the hall or stairway consists of a cold outer wall, it will be difficult to warm the space satisfactorily, especially if there are large windows in any part of it. There will be a warm up draft in one part and a cold down draft in another part, and it is advisable in such a case that all rooms opening into the hall be shut off from it by means of doors. Curtains or draperies cannot be used successfully for this purpose, unless they are made extraordinarily heavy and tight—too heavy, in fact, to be desirable.

If the hall is located in the middle of the building, so that it is warm on both sides, the stairway draft may be utilized

to operate the ventilating system. The foul air may then be drawn out from each room into the hall through the space under the doors, these spaces being made of proper size to serve as foul-air exits. At the top of the stairway, the air should be discharged through an aspirating shaft, and not through a skylight or ventilator. The draft of this shaft should be made as positive as possible by conducting the principal smoke pipe through it. If the air is discharged through the skylight, a current of cold air is likely to enter at one part of the opening, while warm air flows out at another; thus, the cold air will pass down the stairs, making very unpleasant drafts. When the hall is employed in this manner, all the larger rooms, especially those on the first floor, should be provided with additional foul-air outlets. An open fireplace serves excellently for this purpose, provided that the opening into the chimney is not too large, or too far above the floor. A fireplace is a poor contrivance for heating purposes, but it can be made a very useful assistant to ventilation.

59. In dining rooms and parlors, where gas burners or oil lamps are used for illumination, it is a good plan to enclose the lights in glass, and provide them with a special draft tube connected to the foul-air flue. This arrangement not only disposes of the products of combustion, but it will, if properly constructed, add considerably to the brilliancy of the light. It also furnishes a local vent that serves admirably to clear the room of the fumes of cigars, etc.

60. A common attempt at ventilating sleeping rooms is to provide two openings into the hallway, the door being raised an inch or more above the floor, and the transom being opened above it. This method, however, is inoperative, because there is no force tending to drive the air either way through these openings. If any fresh air reaches the occupant of such a room, it will be by leakage through or around the window. If the window is open, and the weather is quiet, the air from the hall is likely to pass through the room and escape at the window, thus making the chamber a

passageway for vitiated air. The air in the hallways is rarely good enough for sleeping rooms, and, as a general rule, should be excluded.

61. The bathroom should be thoroughly ventilated and warmed. As usually constructed in the smaller class of dwellings, the bathroom is but little larger than a closet; when a warm bath is taken, the air is quickly vitiated to a serious degree by the combined effects of moisture, heat, gas burners, and respiration. Where no positive ventilation is provided, this bad air, in conjunction with a warm bath, is very exhausting.

Bathrooms should never be warmed by any device that will vitiate the air, such as gas or oil stoves, or water heaters having no connection to the chimney. A very common method of warming, and at the same time the worst that was ever devised, is by means of a register in the floor, opening into the kitchen or other warm room below. This converts the bathroom into a mere foul-air chamber for the relief of the kitchen.

62. All clothes closets should be ventilated, especially those that receive undergarments or soiled clothing. Dirty clothes or bags containing them should never be permitted in the same closet with clean ones. The openings from these closets should be protected with fine screens to keep out moth millers, etc.

63. The kitchen and laundry should be ventilated independently of the other parts of the house, and if there is any door opening directly from them into the hall or stairways, it should be made practically air-tight; otherwise, the odors of cooking, etc. will pervade the halls and upper rooms. The range should be provided with a hood of liberal dimensions to carry off the hot air and vapors. The vent pipe should connect to a good ventilating flue; if this is not practicable, it may be run to the roof independently. Sometimes it is necessary to provide this pipe with a damper, so that it may be closed when the fire is low, or during stormy weather.

64. The ventilation of the cellar is a matter of great importance to the health of the family, yet in the majority of dwellings no provision is made for it, and it is not even supposed to be necessary. The cellar is usually a reservoir of earth gases and unwholesome emanations from stored vegetables, coal, etc., that should not be permitted to pass into the living rooms. The necessary ventilation can be secured by running a flue from the highest point in the cellar, usually the top of the stairway, to the roof, placing it in some interior wall where it will be reasonably warm. The proper size for this flue depends on the character of the cellar—whether wet or dry—and the nature and quantity of materials stored in it. Ventilation is needed most when the place is both warm and moist, because fermentation then proceeds with the greatest freedom, and molds and fungi flourish vigorously. It is not advisable to merely make an opening into one of the chimneys for ventilating purposes, because it will probably spoil the draft of the stove or heating apparatus connected to it.

The presence of a furnace or boiler in a cellar helps to ventilate it by passing a considerable quantity of air through the fire and up the chimney. The quantity of air thus removed, however, is quite insufficient to provide adequate ventilation unless the cellar is small, very clean, and unusually dry. It should be noted that in this case the air is taken from the floor, instead of near the ceiling as it should be.

65. The first floor in a dwelling should be made gas-tight, in order to prevent the cellar air from passing through and mingling with the air in the living rooms. This is best done by laying the floor in two thicknesses, with a thick layer of tarred paper between them. Ordinary building paper is quite inferior to the tarred material for this purpose. This floor should extend to the outer walls of the building and be made air-tight around the edges, so that no air can possibly pass from the cellar into the spaces between the studding or furring strips. In the cheaper class of frame dwellings, it is a common practice to leave these spaces open, so that they form flues up which the cellar air passes to the attic without

restriction. The ventilation thus afforded, although quite unintentional, has probably saved the inmates of such dwellings, in a multitude of cases, from the sickening effects of bad cellars that otherwise would have been deadly. The existence of these flues or passages is highly objectionable on another account, namely, that they permit heat to escape through the walls with undue rapidity. All circulation of air within them should be prevented, either by putting in tight horizontal partitions at short intervals, or, better still, by filling the spaces with mineral wool or other non-conducting materials. Brick and mortar are not desirable for this purpose, because they absorb a great deal of moisture and tend to rot the woodwork.

FIREPLACE VENTILATION

66. The open fireplace is an efficient form of ventilating apparatus, but is of very little service for heating purposes. It passes so much air up the chimney that the heat radiated from the fire is quite insufficient to warm the fresh air rushing into the room to take its place, to a sufficient degree to be comfortable. It is impracticable to warm rooms satisfactorily by means of the open fireplace, if the external temperature is much below 32°. When the thermometer falls to 10° or lower, it appears as if the room becomes colder the more the fire is made up, until it seems as though the inmates would eventually be frozen. In some cases, fireplaces are constructed so as to warm the fresh air before entering the room, by passing it through a heating flue; but all such arrangements are faulty in principle, and fail to render the fireplace effective as a heating apparatus. The fresh air is delivered so near to the fireplace that it passes almost immediately into the fire, and thus leaves the more remote parts of the room practically as cold as before. The ordinary fireplace wastes 90 per cent. or more of the heat, and even the most improved forms are believed to waste not less than 80 per cent. of the heat given out by the fuel. It is obvious, therefore, that their use is restricted to purposes of ventilation only, to places where there is no objection to expense, and to

localities where the temperature does not fall below the freezing point. They may be employed to good advantage, however, in cold climates, by using them as auxiliaries to the principal heating apparatus, fires being built in them only when the weather is extremely cold.

SUMMER VENTILATION

67. During warm weather, when the heating apparatus is not required, a building can be abundantly flushed with air by opening the doors and windows. It is necessary, nevertheless, to make provision for proper ventilation during stormy weather, when all outer doors and windows must be closed. To accomplish this, a register should be provided near the ceiling of each room, in addition to that near the floor, because the latter is practically inoperative at this season to provide for the escape of foul air. Top or ceiling registers are suitable only for summer use, and should be tightly closed at the end of the season when the heating apparatus is started up.

Particular attention must be given to the ventilation of the cellar. Every window should be kept open continuously, and the outer doors should never be closed except during storms. Strict cleanliness should be enforced at all points, and the air should be kept as sweet and fresh as in the living rooms. If it is practicable to admit sunlight, it should always be done.

The arrangements usually employed to shut out the excess of sunlight from living rooms and chambers are fatal to good ventilation. Draped curtains are usually hung so high and so close to the casings that they prevent the flow of air either way through the upper half of the window. The rolled curtains or shades, as commonly applied, are equally obstructive. All such curtains should be hung so that there will be a clear space of $1\frac{1}{2}$ or 2 inches above the roller, for the passage of air. The top sash being lowered, the curtain can then be pulled down to the bottom without shutting off the air supply.

In applying screens of wire cloth or mosquito netting, to keep out insects, etc., it should be borne in mind that the flow of air through those materials is only about one-fourth of that through a clear space of equal area.

EXAMPLE OF RESIDENCE VENTILATION

68. Figs. 24 to 28 show the arrangement of flues and apparatus for ventilating and heating a suburban residence

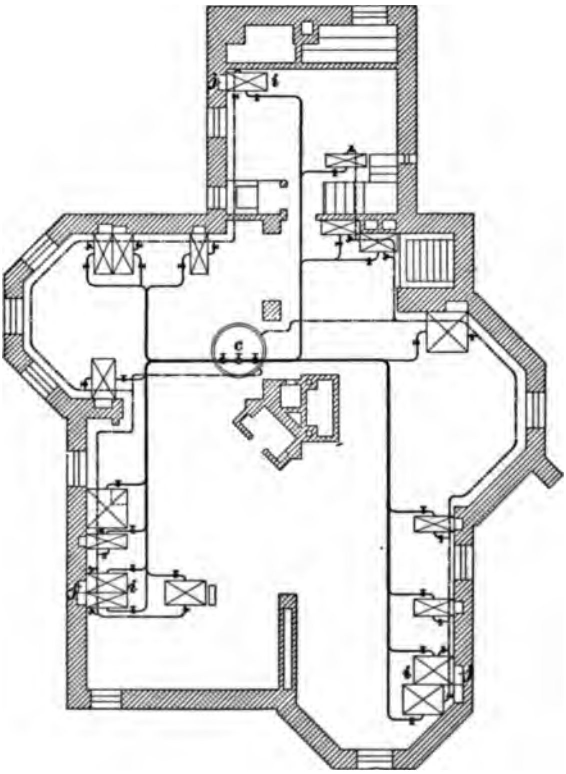


FIG. 24

of moderate size. The ventilation is effected by an aspirating chimney, and the heating is performed by indirect hot-water apparatus.

The aspirating chimney *a*, Figs. 25 to 28, is 25 inches square inside, and the draft is aided by a 10-inch smoke pipe that passes up through it from the boiler. Another aspirating chimney *b*, Figs. 25 to 28, is provided in the kitchen for the use of the rear part of the house. This latter chimney is made 18 inches square, and the smoke pipe within it

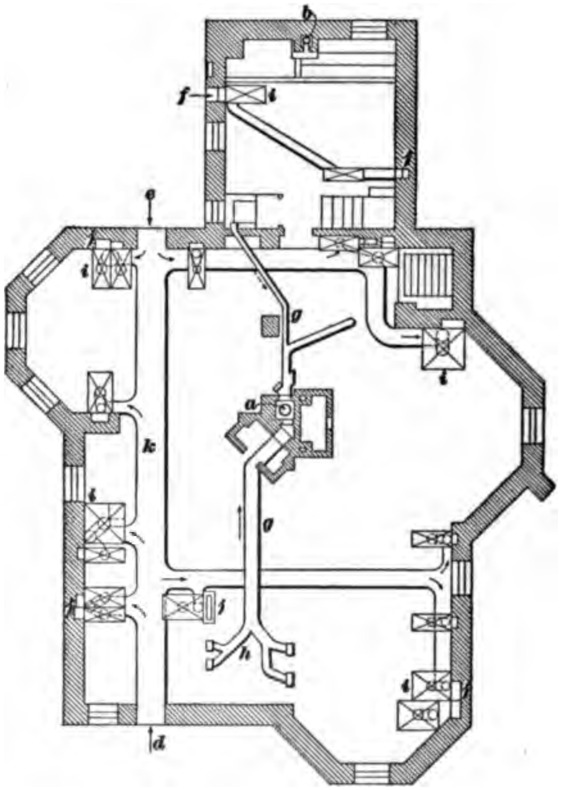


FIG. 25

is 8 inches in diameter. The water closets are local-vented by this chimney instead of the other, so that effective ventilation may be had at all seasons of the year. Figs. 24 and 25 are both basement plans, one showing the radiator stacks *i* and hot-water piping, and the other showing the cold-air

ducts *k* and the main foul-air flues that discharge into the central chimney. The flow pipes are shown in solid lines, while the returns are indicated by dotted lines. The boiler is shown at *c*, Fig. 24. The cold air enters through windows

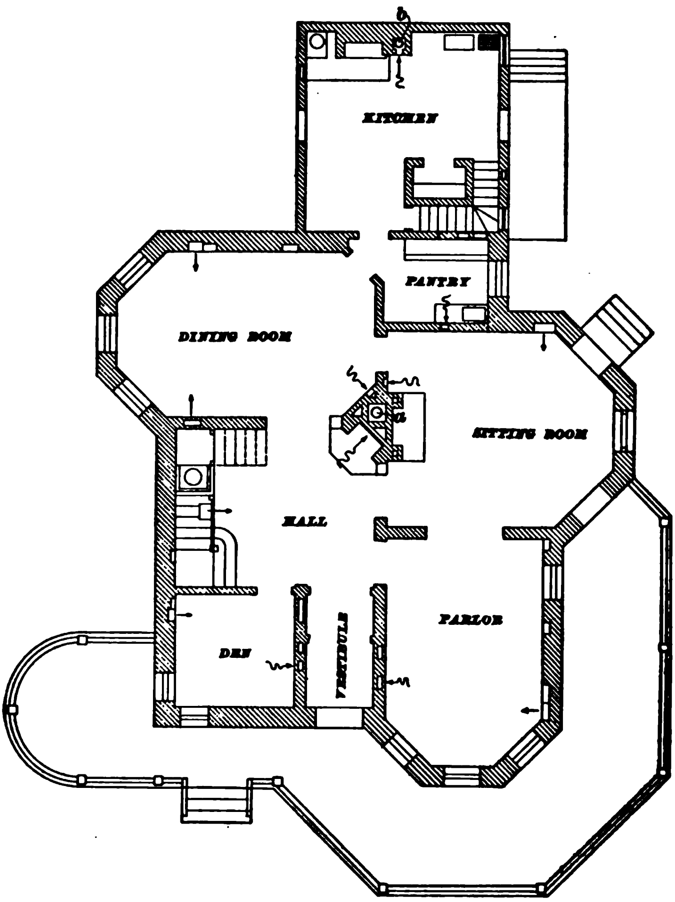


FIG. 26

at *d*, *e*, and *f*, Fig. 25, the last named being for the radiators in the rear. It then enters the casings of the indirect stacks on their under side, passes up between the radiator surfaces, and flows into the several rooms through the hot-air

flues j, j, Figs. 24 and 25, that are built in the walls. All the foul-air ducts from the rooms on the first and second floors are led downwards to the basement, where they connect with the main flues g, h, Fig. 25. On the third floor,

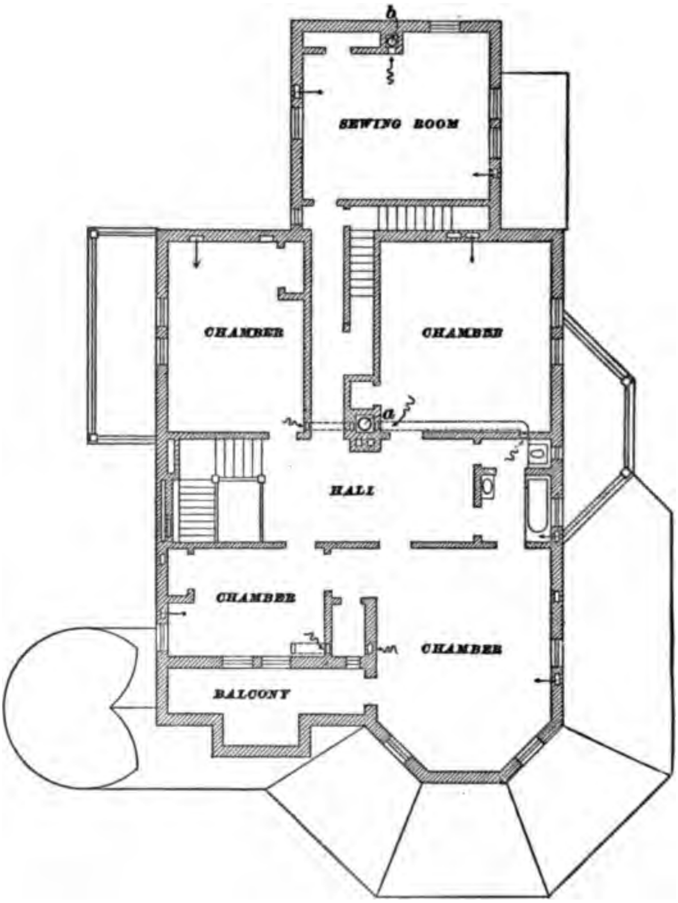


FIG. 27

however, they discharge directly into the chimney, as shown in Fig. 28. All the hot-air inlets are located about 6 inches below the ceiling, and the foul-air outlets are placed on the opposite side of the room, just above the baseboard. It will

be noted that the warm-air registers are located in cold outer walls, while the foul-air ducts are run only in warm interior walls.

UNSANITARY DRY-CLOSET ARRANGEMENT

69. The problem of disposing of the sewage matter from schoolhouses is sometimes a difficult one, especially where no water supply is available for water closets. A system designed to meet the requirements of such cases has within recent years been introduced under the name of the **dry-closet system.** This should not be confounded with the well-known *dry-earth system*, which is quite unobjectionable on sanitary grounds. This dry-closet system is operated by an aspirating chimney, frequently the same one that serves to convey the foul air from the schoolrooms. The closet seats are located in the roof of a tunnel leading to the chimney, and each seat is provided with a cover intended to be kept closed when

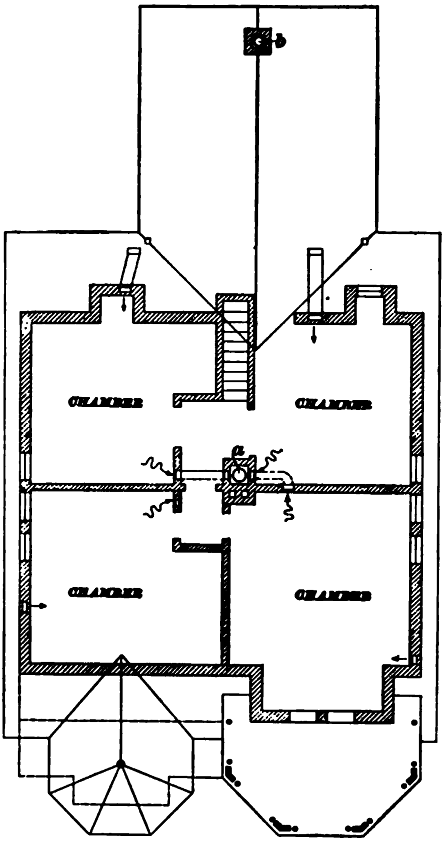


Fig. 28

not in use. The liquids are sometimes drained off, but the solid matter remains on the floor of the tunnel, and is gradually dried by the current of air that passes over it to the

chimney. At the end of the school term, the deposits are saturated with kerosene and then destroyed by fire.

The foul air from the schoolrooms is drawn directly through the tunnel; consequently, whenever a blow-down occurs, not only is the foul air driven back into the rooms, but the noxious odor of the tunnel is carried back with it.

As drying and evaporation can take place only by absorbing heat from the air-current, it is evident that the temperature of the foul air will be lowered somewhat, and the draft of the chimney will be correspondingly weakened. Sometimes a small grate fire is maintained at the entrance to the tunnel or the base of the chimney, to maintain the draft in mild or warm weather, when the heating apparatus is not in use.

In some cases, a separate chimney is provided for the dry closet, and the air is taken only from the room containing the apparatus. The result of a blow-down, however, is the same as in the previous case, except that the communication with the interior room is a little less direct.

The seats in these dry closets are always at a higher level than the inlet for air; consequently, the foul air in the tunnel always tends to flow into the room whenever a cover is raised. Usually the chimney draft is sufficient to counteract this tendency and prevent any outflow, so long as only one or two covers are opened; but when all the seats are in use at the same time, as often happens at recess and other occasions, the draft is wholly inadequate. It is then found that while air flows inwards at a few of the seats nearest the chimney, the vile tunnel air flows out unchecked at the others.

Another very serious objection to this system is that much of the fecal matter is reduced, by drying, to the condition of dust, and is carried up the chimney. If this matter happens to be infested with the germs of contagious diseases, these also are dried and projected into the atmosphere. In fact, matter is thus carried into the air that should go into the earth. All dust eventually descends to the level at which people breathe; thus, the effect of this apparatus is to disseminate filth and disease germs broadcast over the

surrounding country. The dry-earth system, in which all fecal matter is mixed with dry absorbent materials, is free from all such objections.

The dry-closet system of heating and ventilating schoolhouses is one of the worst disease breeders that can be devised in schoolhouse construction.

If dry closets must be used, they should be located outside of the main building and be ventilated separately.

SCHOOLHOUSE VENTILATION

70. Modern schoolhouse requirements are briefly stated in the following form of a bill, or act, providing for the heating, lighting, and ventilating of public schoolhouses, prepared by the Committee on School Legislation, consisting of one member from each state and territory of the United States, appointed by the Department of School Administration of the National Educational Association, and adopted at its Minneapolis meeting of July 11, 1902:

SEC. 1. It shall hereafter be unlawful to let any contract for or to construct any public schoolhouse, or other building, to be thereafter used for school purposes, the lighting, heating, and ventilation of which is not in full accord with the provisions of this act.

SEC. 2. All public school buildings hereafter constructed or remodeled for school purposes, must be lighted by windows placed in one rear or side wall of each class and study room, and such windows shall contain glass surface of not less than one-fifth of the floor space of each room; and all desks and seats shall be so arranged that the windows will be on the left, or in the rear, so far as possible, of the pupils.

SEC. 3. All class and study rooms shall contain not less than 15 square feet of floor space and not less than 180 cubic feet of air space for each pupil.

SEC. 4. All public schoolhouses or school buildings of more than three rooms each, which shall hereafter be constructed, or remodeled for school purposes, must be provided with such heating and ventilating apparatus as will facilitate

the introduction of warm air, when occasion requires, into each class or study room, not less than 8 feet above the floor line, with provision for the exit of impure air at the floor line; and the whole shall be so arranged that the required temperature of 70° can be maintained throughout each room even in the coldest weather, and the air changed in each room (combined average measured at inlet and exit openings) at least eight times in each hour without lowering the temperature or creating a noticeable draft at or below the breathing line.

SEC. 5. All closets and urinals must be so constructed as to provide for the absolute seclusion of the pupil using the same. They must also be provided with vent flues, so arranged that all foul odors and air will be carried out below breathing line.

SEC. 6. Any contract for the construction or remodeling of any school building, not in conformity with the requirements of this act, shall be void; and any public school officer or contractor, who shall violate the terms and conditions of this act, by letting or accepting any contract for the construction or remodeling of any public schoolhouse or school building, not in conformity with this act, shall be deemed guilty of a misdemeanor, and shall be subject to a fine of not less than two hundred dollars, nor more than one thousand dollars for each offense.
